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Decision Support for Renewal of Wastewater Collection and Water Distribution Systems

SCIENCE

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DECISION SUPPORT FOR RENEWAL OF WASTEWATER COLLECTION AND WATER DISTRIBUTION SYSTEMS

by

Dr. John Matthews and Wendy Condit, PE
Battelle

Dr. Rob McKim, PE
Trenchless Technology Center at Louisiana Tech University

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Dr. Ariamalar Selvakumar, PE
Task Order Manager

U.S. Environmental Protection Agency
Urban Watershed Branch
National Risk Management Research Laboratory
Water Supply and Water Resources Division
2890 Woodbridge Avenue (MS-104)
Edison, NJ 08837

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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FOREWORD

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EXECUTIVE SUMMARY

Introduction

The decision of how to accomplish the renewal of existing wastewater collection and water distribution systems involves the evaluation of many criteria and parameters. These criteria must be evaluated thoroughly to determine the optimal approach for rehabilitating or replacing these systems efficiently and cost-effectively. The objective of this report is to: identify the current decision support methodologies, models and approaches being used for determining how to rehabilitate or replace underground utilities; identify the critical gaps of these current models through comparison with case history data collected from utilities; and assess the feasibility of substantially improving upon existing approaches.

This report describes the current state of decision support models and methodologies used throughout the U.S. for determining how to decide whether to rehabilitate or replace existing wastewater collection or water distribution pipes. Eight case studies are provided to document how some of the major population centers throughout the U.S. make their decisions. Each case study provides the parameters, criteria and model, if any, that was used in each city's typical method selection process. The water and wastewater utilities that were visited and surveyed include those located in: Atlanta, GA; Columbus, OH; Dallas, TX; Indianapolis, IN; Las Vegas, NV; Los Angeles, CA; Miami-Dade County, FL; and New York City, NY.

Review of Existing Models

Only a few decision support models are commercially or publically available for the selection of rehabilitation or replacement technologies. However, this review identified 20 models reported in the research literature over the past 15 years capable of that process. The lack of widespread model utilization is due to the fact that most utilities make their decisions based on in-house or hired consultant expertise; however, the need for more systematic decision support processes is recognized by both parties. The models reviewed are divided into three groups: 1) general models applicable to both wastewater collection and drinking water distribution systems; 2) models specific to wastewater collection systems; and 3) models specific to drinking water distribution systems.

The seven most complete models were presented and evaluated based on their ability to perform the critical functions of decision support such as: processing condition assessment data; screening multiple technologies based on various technical parameters; performing cost analysis; and ranking applicable technologies. Of the models reviewed, two models (one wastewater specific and one water specific) were identified as able to perform these critical functions, although neither has been documented as being widely used by utilities. Data were sought from multiple utilities to determine what their specific decision support needs were and the critical gaps of the currently available decision support models.

Review of Utility Approaches

Eight utilities were visited and interviewed in order to acquire data on their decision-making approaches and to identify their decision support needs. The interviews helped to identify how each of the major utilities are making their rehabilitation versus replacement decisions by determining which technologies are typically used and what parameters and tools are used to select the proper technology. Three utilities used a decision support model in their method selection process, and in each case the model was developed and tailored solely for their use. The strengths and limitations of each model were documented and the critical gaps were indentified based on utility input and comparison to other decision approaches, including key variables and functions.

Critical Gaps of Models

While each utility is capable of performing the critical decision functions to determine whether to use rehabilitation or replacement technologies for pipeline renewal, the need for model support to assist in this process was identified by almost all of the utilities interviewed. In addition to the critical components mentioned above, other crucial tool necessities that were identified more than 75% of the time included: access to more alternative rehabilitation options and data; access to regional cost data for each technology; access to technology case histories, specifically for new or emerging methods; and access to utility users that have used the technology for further information about applicability and lessons learned. Many of the reviewed models provided alternatives and cost data, but they did not contain detailed case studies and contact information for utility users which were both seen as important aspects of any decision support system (DSS).

Recommendations for Improving Models

Four models from the literature and utility interviews are identified as offering examples of best practices in decision support. If the functionality of these models were combined, a more comprehensive model would meet each of the critical components and crucial necessities identified by utilities. This would create a fully functional decision support tool for identifying when to use rehabilitation or replacement methods and which technology is the most cost-effective and efficient. In all cases, the primary gap identified is the lack of readily available case study information.

It is feasible to substantially improve upon the best methodologies by incorporating aspects of each model into a single, more comprehensive model for decision support. This improved tool could include: the Trenchless Assessment Guide for Rehabilitation (TAG-R) structure, which contains a robust method database and an industry vetted technical evaluation process; a condition assessment evaluation, which contains a detailed approach for including defect codes into the wastewater technology selection process (Halfawy et al., 2008); a deterioration model, which incorporates breakage and deterioration data into the water technology selection process (Ammar et al., 2010); and the City of Atlanta's Rehabilitation Selection Tool, which has the most developed platform for including cost data and parameters for specific technologies that could be expanded for each of the methods available in the database. After incorporating each of these aspects into one model, the inclusion of a case study database would be needed to meet the final need identified by utilities.

The task of building such a model is feasible, but it would require the resources and capabilities of a team tied to all aspects of the water and wastewater industry, a team with a model development background and support from key agencies such as the Water Environmental Research Foundation (WERF), Water Research Foundation (WaterRF), National Association of Sewer Service Companies (NASSCO), National Utility Contractors Association (NUCA), and the Environmental Protection Agency (EPA) to ensure that the key stakeholders (i.e., utilities, contractors, and technology manufacturers) were involved in the model development and implementation.

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ACRONYMS AND ABBREVIATIONS

60 MP	60 Miles Program
ACI	American Concrete Institute
AHP	Analytical Hierarchy Process
AM	Asset Management
ARP	Annual Rehabilitation Planning
AWI	Aging Water Infrastructure
AWWA	American Water Works Association
CARE-S	Computer Aided Rehabilitation of Sewer Networks
CARE-W	Computer Aided Rehabilitation of Water Networks
CBD	Central Business District
CCTV	Closed-Circuit Television
CD	Consent Decree
CDSS	Comprehensive Decision Support System
CIP	Capital Improvement Project
CIPP	Cured-In-Place Pipe
CM	Cost Module
CMOM	Capacity Management Operations and Maintenance
CSO	Combined Sewer Overflow
DARS	Difficult Access Reaches Program
DBMS	Database Management System
DDC	New York City's Department of Design and Construction
DEP	New York City's Department of Environmental Protection
DPU	Columbus Department of Public Utilities
DPW	Department of Public Works
DSS	Decision Support System
DWU	Dallas Water Utilities
D-WARP	Distribution – Water Mains Renewal Planner
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
GPS	Global Positioning System
GSTT	German Society for Trenchless Technology
HDD	Horizontal Directional Drilling
HDPE	High Density Polyethylene
IAB	Industry Advisory Board
I/I	Inflow and/or Infiltration
ILI	Infrastructure Leak Index
I-WARP	Individual – Water Main Renewal Planner
in.	Inches
LCCA	Life Cycle Cost Analysis
lf	Linear Feet
LVVWD	Las Vegas Valley Water District

MRP	Mains Replacement Prioritization
MWH	Montgomery Watson Harza
NASSCO	National Association of Sewer Service Companies
NHPP	Non-Homogeneous Poisson Process
NRCC	National Research Council Canada
NRMRL	National Risk Management Research Laboratory
NUCA	National Utility Contractors Association
PACP	Pipeline Assessment Certification Program
PHM	Proportional Hazard Model
PI	Performance Indicator
PMT	Atlanta's Program Management Team
PVC	Polyvinyl Chloride
QA	Quality Assurance
QSR	Quick Structural Rating
RCP	Reinforced Concrete Pipe
RDP	Rehabilitation Design Program
ROW	Right-Of-Way
RST	Rehabilitation Selection Tool
RWQCB	Regional Water Quality Control Board
SMARTS	Sewer Management Automated Repair Tracking System
SNWA	Southern Nevada Water Authority
SPOT	Sewer Planning Optimization Tool
SRM	Sewer Rehabilitation Manual
SSES	Sanitary Sewer Evaluation Survey
SSO	Sanitary Sewer Overflows
STREAMS	Scientific, Technical, Research, Engineering, and Modeling Support
TAG	Trenchless Assessment Guide
TAG-R	Trenchless Assessment Guide for Rehabilitation
TCEQ	Texas Commission on Environmental Quality
TIP	Tight-In-Pipe
TO	Task Order
TSM	Technology Selection Module
TTC	Trenchless Technology Center
WASD	Water and Sewer Department
WCD	Wastewater Collection Division
WCE	Wastewater Conveyance Engineering Division
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WES	Wastewater Engineering Services
WRc	UK Water Research Centre
WaterRF	Water Research Foundation

1.0: INTRODUCTION

1.1 Project Background

Even with a comprehensive set of fully effective rehabilitation technologies, many issues still remain about which technologies to use and how and when to apply them. Some of the issues affecting renewal planning include: (1) the condition of a system; (2) the extent of the necessary repairs; (3) the availability of funds for the work; and (4) the ability to assess the condition of each component of the system. Depending on the specific conditions of a given utility, its rehabilitation approach may include partial rehabilitations to extend performance life as well as full structural rehabilitations to reset the life cycle performance clock. Selecting the most appropriate and cost-effective solution depends on many aspects which are difficult to quantify and usually poorly understood. However, there are several factors that apply directly to the selection of rehabilitation methods which have a strong bearing on the cost-effectiveness of rehabilitation programs (EPA, 2009).

As part of the U.S. Environmental Protection Agency (EPA)'s Aging Water Infrastructure (AWI) Research Program, one key area of research that was pursued, in collaboration with water and wastewater utilities, was a study of the current approaches available and used for making rehabilitation versus replacement decisions. The purpose of this study was to conduct an extensive literature review of the current approaches as well as a review of water and wastewater utility's practices, including the compilation of eight case studies from municipalities across the U.S. Once the two sets of information were compiled and analyzed, the critical gaps of the best approaches could be analyzed and recommendations could be made as to the feasibility of implementing significant and necessary improvements to the currently available models (EPA, 2007). This report documents the objectives, findings, and recommendations for Task 6 of the Scientific, Technical, Research, Engineering, and Modeling Support (STREAMS) contract Task Order (TO) 58 titled *Rehabilitation for Wastewater Collection and Water Distribution Systems*.

1.2 Objectives Defined

The report is intended to meet the following four objectives:

- Conduct an extensive literature review to identify current methodologies and decision support models for determining how to rehabilitate or replace underground utilities.
- Collect data and case histories from eight cities or utilities, which will include the parameters, criteria, and model, if any, used in each city's typical technology decision process.
- Identify critical gaps in the current models outlined in the literature review through comparison with the methodologies and case history data obtained in Objective #2.
- Assess the feasibility of substantially improving upon existing approaches and provide recommendations of implementing the improvements.

1.3 Report Outline

This report is organized based on the four objectives mentioned above. The following sections are included in the report describing the execution of each of the objectives:

<u>2.0 Review of Decision Support Systems Models</u>
The capabilities, inputs and outputs, benefits and limitations, and critical gaps in applicability, performance, data, and affordability for each model or approach are described.

3.0 Case Studies of Renewal Decision-Making Approaches

Eight utilities were interviewed regarding their decision-making approaches, which were then documented and catalogued in terms of capabilities, inputs and outputs, benefits and limitations, and critical gaps.

4.0 Critical Gaps of Current Models and Approaches

This section provides an overview and synthesis of the information provided in Sections 2 and 3 and identifies the critical gaps of both sets of models and approaches.

5.0 Recommendations for Improving upon Existing Approaches

Assesses the feasibility of improving upon the best current approaches and discusses an implementation plan.

2.0: REVIEW OF DECISION SUPPORT SYSTEM MODELS

There are very few decision support models currently available for the selection of rehabilitation or replacement technologies in the U.S. The primary mode of technology selection comes from three areas: (1) the use of in-house engineers and designers from municipalities or utilities to make decisions based on their experience and research; (2) use of hired consultants to make recommendations, some of which use matrices (i.e., Ortega and Metcalf, 2010), decision trees or even automated programs, many of which are proprietary; and (3) internally developed matrices, decision trees or automated programs to make their recommendations. The literature review below presents the models and tools which have been proposed over the past 15 years for the selection of water and wastewater rehabilitation and replacement technologies in the U.S. and worldwide. The models are divided into three groups: (1) general models, capable of selecting technologies for both water and wastewater systems; (2) wastewater specific models; and (3) water specific models. Each model is judged based on its ability to perform the five critical components shown in Table 2-1.

Table 2-1. Critical Components of Rehabilitation and Replacement Decision Models

No.	Critical Component
1	Ability to process condition assessment and pipe defect data
2	Contains an extensive method database of technologies and their technical parameters
3	Performs a technical evaluation of the project, host pipe, and site conditions
4	Performs a cost analysis
5	Performs a final method ranking

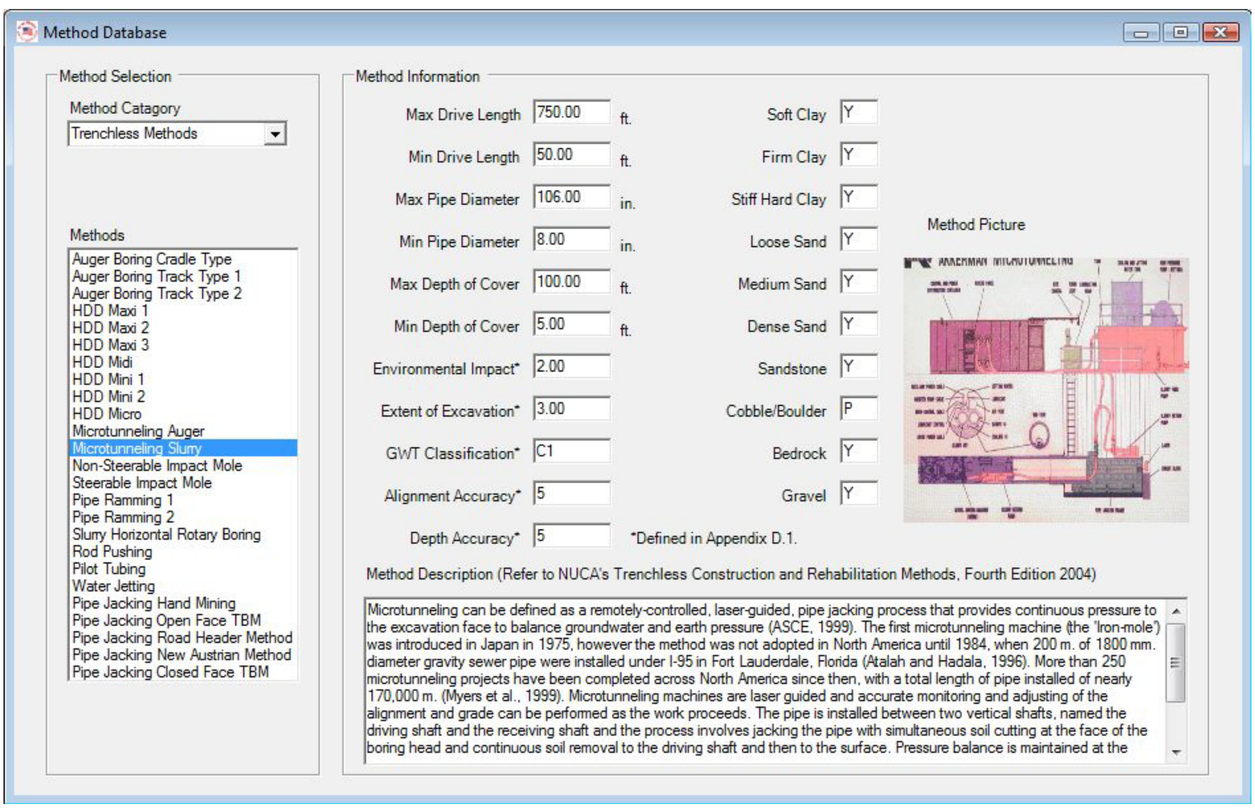
This review does not describe the many rehabilitation planning and prioritization asset management tools which are used primarily to determine when to remediate which assets. One such model, developed by Fenner and Sweeting (1999) for planning rehabilitation for 80% of sewers which are classified as non-critical sewers in the UK, used sewer performance and asset data from geographic information systems (GIS) to rank grid squares into various zones for rehabilitation action in phase one. Phase two used a Bayesian statistical analysis of each pipe length within each grid square most at risk for a failure (Fenner and Sweeting, 1999). Most of these systems determine the likelihood of failure and consequence of failure to prioritize which segments need to be renewed. These systems attempt to balance a reduction of long-term cumulative cost against an increase in the failure probability, but they do not focus on how to perform the renewal. Reviews of such systems are provided in Ana and Bauwens (2007); Moglia et al. (2006); Halfawy et al. (2005; 2006); Stone et al. (2001); and Fenner (2000).

2.1 General Models

Hastak and Gokhale (2000) were the first to develop an automated general model for evaluating and selecting rehabilitation technologies for both sewer and water in which they used the analytical hierarchy process (AHP) to evaluate common decision parameters. Some of the parameters included the user's requirements, site characteristics, soil characteristics, condition of the host pipe, and design life of the new pipe or liner (Hastak and Gokhale, 2000). This led to further developments and improvements and sister software which performs similar functions (Hastak et al., 2005).

Two general method selection models have been developed in recent years to assist municipal users with their method selection decisions (i.e., Trenchless Assessment Guide [TAG] and Trenchless Assessment Guide for Rehabilitation [TAG-R] which are described below in detail). TAG has been available as standalone software through the National Utility Contractors Association (NUCA) since 2006; TAG-R has been available through the National Association for Sewer Service Companies (NASSCO) since 2008. A combination of the two has been available online through the Trenchless Technology Center (TTC) at Louisiana Tech University since 2008 (Matthews and Allouche, 2009). Matthews (2010) also proposed an integrated, multi-attribute general model which takes into account direct as well as social costs, in addition to project site and pipe characteristics. The TAG/TAG-R approach is discussed at length below followed by a summary of other general methods.

2.1.1 TAG/TAG-R. The decision support system (DSS) TAG focuses on the selection of construction methods for installation or off-line replacement of sewer pipes and TAG-R focuses on rehabilitation technologies. Both are capable of evaluating pipelines for individual drive lengths and determining what methods are technically viable by comparing user supplied, project specific input parameters that are compared against industry vetted method data which is housed in a searchable database. TAG contains technical data for more than 25 technologies capable of installing or replacing pipelines and TAG-R contains more than 80 methods for rehabilitation of wastewater, water, and manhole systems (Matthews et al., 2005; Matthews, 2010). Figure 2-1 shows a screen shot of the technology database which is provided as an information source in addition to being the data against which the project parameters are compared.



igure 2-1. Screen Shot of TAG Method Database

The primary function of TAG and TAG-R is to perform a technical evaluation of the project specific data compared to the database values for each technology and to then rank the viable technologies in terms of associated risk for the TAG program. TAG-R does not currently have a risk assessment module. The types of user input values for TAG and TAG-R are included in Tables 2-2 and 2-3, respectively.

Table 2-2. Evaluation Parameters of TAG

Evaluation Parameters of TAG	Input
Type of Problems	Structural or Capacity
Technologies to Consider	New Installation and/or Inline Replacement
Drive Length	Number (ft)
Pipe Diameter (ID)	Number (in.)
Depth (to Crown)	Number (ft)
Depth to Ground Water Table	Number (ft)
Alignment Accuracy Required	Very Low to Very High (Defined)
Profile Accuracy Required	Very Low to Very High (Defined)
Soil Types along the Alignment	% of Total Alignment Length
Host Pipe Material (1 out of 10)	Selected from a list
New Pipe Material (up to 10)	Selected from a list
Excessive Sagging in the Host Pipe	Yes or No
Upsize Greater than 2.5 times Required	Yes or No

Table 2-3. Evaluation Parameters of TAG-R

Evaluation Parameters of TAG-R	Input
Technologies to Consider	Rehabilitation
System Needing Rehabilitation	Sewer, Water, Lateral, and Manholes
Length	Number (ft)
Pipe Diameter (ID)	Number (in.)
Deterioration Level	Fully or Partially
Cross-Sectional Reduction Allowed	Small, Medium or Large
Access Allowed	Manhole, Access Pit or Cleanout
Bends Allowed	Largest of Host Pipe Bend (° Bend)
Cross-Sectional Shape	Circular or Box-Shaped
Operating Pressure	Range: Low, Medium or High
Services Reconnected	Internally or Externally
NSF Standard 61	Yes or No
Diameter Size Changes	Yes or No
Reverse Crown Curvature	Yes or No

Each of the decision support programs evaluates the user input parameters against the database values for each technology in the appropriate data table. In each case, the evaluation will produce a list of technically applicable technologies and in the case of TAG; a risk analysis will be performed to rank the alternatives versus project specific parameters. Six individual risk parameters, which are shown in Table 2-4, are then weighted and plugged into a risk equation that produces final risks scores (Matthews et al., 2006).

Table 2-4. Risk Parameters of TAG

Risk Parameters	Determined by
Length Ratio	Percent of the Maximum Database Value
Diameter Ratio	Percent of the Maximum Database Value
Depth Ratio	Percent of the Maximum Database Value
SET Index	Availability of Specs, Owner's Experience, and Track Record
Environmental Impact	Included in Database for Each Technology
Site Accessibility	Range: No Accessibility to High Accessibility (Green Field)

The output includes the technically viable methods and their associated relative risk ranking for TAG or simply the technically viable methods for TAG-R. Each program was scrutinized by separate industry expert panels and validated against multiple case studies (Matthews et al., 2007). The two programs have since been combined into a single Web-based application which is currently being offered at no cost at www.tagronline.com (Matthews and Allouche, 2009).

2.1.2 Critical Gaps of TAG/TAG-R. Critical gaps of TAG and TAG-R include: the lack of technology or bid item related costs; detailed capacity reduction allowance or hydraulic modeling; type of bypass required (i.e., internal or above ground), which relates to bid item details; number or size of access pits, which affects cost; or any other item that may affect cost of using a technology. The effect of cost was taken into account in later work proposed in Matthews (2010), but this has not been implemented or provided for public use. The program does take into account the types of issues facing the user (e.g., capacity or structural issues), but it does not take into account specific defect or defect codes which could also be seen as a gap. Despite these deficiencies, TAG-R is the only known tool currently capable of evaluating specific pipe segments for force mains, gravity sewer, water mains, laterals, and manholes in terms of appropriate rehabilitation, replacement, and repair technologies.

2.1.3 Summary of Other General Models. A framework was recently proposed by Virginia Tech University. This model approach was constructed similarly to TAG-R by determining the type of problem; cause of the problem; pipe characteristics; and project requirements (Maniar, 2010). Another framework incorporates water, sewer, and road infrastructure assets into the decision-making process, but this model is still in the development stage (Shahata and Zayed, 2010). Of the five models described above, only Matthews (2010) includes four of the five critical components of a comprehensive decision support system. The four components include: an extensive (i.e., many commonly used technologies and their associated technical parameters) method database; the technical evaluation of the project conditions and characteristics; a cost analysis; and a final method ranking. None of the models has the ability to process condition assessment data even though each accounts for pipe condition to some degree. A summary of the general models available and their associated capabilities is shown in Table 2-5.

Table 2-5. Summary of General Models

Models, Year	Defect Database	Extensive Method Database	Technical Evaluation	Cost Analysis	Method Ranking
TAG, 2006	No	Yes	Yes	No	Yes
TAG-R, 2008	No	Yes	Yes	No	No
Matthews, 2010	No	Yes	Yes	Yes	Yes
Maniar, 2010	No	Yes	Yes	No	Yes
Hastak and Gokhale, 2005	No	No	Yes	Yes	Yes

2.2 Wastewater Specific Guidelines and Models

Models and guidelines applied to wastewater decision support, which can be utilized without having to be customized, have been developed and in use for more than 25 years through various national research organizations, including the German Society for Trenchless Technology (GSTT). The GSTT, in collaboration with industry, developed a basic guide for pipe construction and rehabilitation in the mid-1990s. This guideline enables the user to evaluate (for a specific problem) available methods for repairing, renovating or renewing of utility networks using either open trench or trenchless construction methods. In order to make the guide user friendly and readily available, the printed version was converted to a computer-based, expert-rule-based decision support system. The system features multi-media capabilities with an in-house limited library of various methods and hyperlinks to external sources of information (Matthews, 2006).

Some more recent guidelines include the *Existing Sewer Evaluation and Rehabilitation Manual* (Water Environment Federation [WEF], 2009), which is currently in its third edition and includes a method selection process that takes into consideration: structural and nonstructural conditions and defects; hydraulic capacity issues; surface and subsurface conditions; and other constructability issues such as lateral reinstatement and bypass pumping. In the UK, a similar manual known as the *Sewer Rehabilitation Manual* (SRM), has been a key document for the planning of rehabilitation work on existing sewer systems since 1983 and it has recently been incorporated into an online resource called the Sewerage Risk Management Web site (UK Water Research Center [WRc], 2010). In Canada, the National Guide to Sustainable Infrastructure or InfraGuide, operated from 2001 to 2007 online and provided a set of guidelines and a proposed decision model for the selection of rehabilitation technologies for both the installation and replacement of wastewater pipes (National Research Council Canada [NRCC], 2007). When utilizing written guidelines, there is always the need to keep them updated which is why more are being published in online formats. The fact that technologies are constantly changing and improving their technical capabilities creates the need for easily updated resources.

In addition to these national published guidelines, various systems have been proposed for the selection of methods for rehabilitating or replacing a sewer pipe (Matthews, 2006; 2010). These models have evolved from decision trees to fully automated and integrated decision support systems. Duggan and Doherty (1995) developed a guide that provides criteria for method selection and a subsequent ranking based on criteria weighting. The seven selection criteria include: (1) applicability to existing conditions; (2) reduction of infiltration; (3) prevention of surcharge; (4) improvement of capacity; (5) minimization of social impacts; (6) cost-effectiveness; and (7) improvement of long-term maintenance. Bielecki and Stein (1997) developed a process that began by: defining the problem type; cause and extent of the damage; the physical characteristics of the host pipe; and the needed remedial action. Next, criteria from four areas, such as environmental and economic, are assessed for each method and the associated points are calculated with the method having the most points and lowest cost being selected.

McKim (1997) proposed a hierarchy-based model that breaks the elements of each technology into three components (i.e., performance, function, and capacity) and compares these capabilities to the project's requirements. The model, which is applicable for gravity driven systems, focuses on technical issues and is intended to provide the decision-maker with a starting point by eliminating inappropriate methods. Abraham et al. (1998) proposed a process for rehabilitation of large combined sewers which indicated: (1) shotcrete as the low cost option in low flow pipes with no corrosion; (2) cured in place pipe (CIPP) as the best option for internal corrosion in low flow pipes less than 72 in.; and (3) sliplining with a fiberglass reinforced felt liner as the best option for pipes larger than 72 in. with open cut using reinforced concrete pipe (RCP) as the alternative in all other cases.

Shahab-Eldeen and Moselhi (2001) proposed a model for rehabilitation of concrete and clay sewer pipes, which includes two components: (1) a Database Management System (DBMS); and (2) a DSS. The user input includes pipe defect type, condition rating, pipe diameter, and pipe material and the database includes types of defects and data for four rehabilitation methods. Diab and Morand (2001; 2003) proposed a model that included an elimination phase based on the type of problem (i.e., structural or capacity) and a multi-criteria analysis based on the performance criteria of each method. The criteria are: effect on capacity; structural capabilities; installation and indirect social costs; and material design life. Plenker (2002) proposed an expert-based model based on: the nature of the damage; whether it needs to be completed immediately or at a future date; and whether a spot repair or extensive renovation is needed. In each case, alternatives are proposed and the direct and indirect costs associated with each technique are then evaluated based on short-term cost as well as life cycle cost analyses.

Bairaktaris et al. (2007) developed a system in Greece for processing closed-circuit television (CCTV) data using a neural network classifier to identify cracks in the pipe. Next, the local and global structural integrity of the pipe is determined; appropriate methods are chosen based on host pipe and site conditions; and the residual present value plus a consideration of service life is taken into account to determine the most cost-effective method. Schroeder et al. (2008) developed a tool that extracts sewer defects from a GIS database and identifies solutions and priorities for each pipe section. The tool stores CCTV data in Pipeline Assessment Certification Program (PACP) format in a GIS map and a course of action is determined based on these data. The tool was successfully applied to an inflow/infiltration (I/I) study for the City of Columbus and other national programs that have large amounts of sewer inspection data (Schroeder and Fallara, 2010).

None of these systems are currently being used widely in the U.S., but many have served as precursors to the development of systems such as TAG and TAG-R (Duggan and Doherty, 1995; Bielecki and Stein, 1997; McKim, 1997; Abraham et al., 1998; Shahab-Eldeen and Moselhi, 2001; Hastak and Gokhale, 2000). As mentioned earlier, one of the critical gaps of TAG-R is the lack of cost data and cost factor information. The incorporation of a proposed model to include appropriate cost data to quantitatively evaluate and compare direct and indirect (i.e., social) costs of traditional open cut and trenchless technology methods would fill this critical gap while creating a comprehensive DSS for the selection of appropriate technologies (Plenker, 2002; Diab and Morand, 2003; Jung and Sinha, 2007; and Matthews, 2010). The need to incorporate condition assessment data is another gap of TAG-R cited earlier, that could be implanted in similar formats described in the literature (Bairaktaris et al., 2007; Schroeder et al., 2008). Two recent models have been developed abroad that incorporate the several parameters for a comprehensive decision support tool as it relates to sewer renewal decisions, which are described in more detail below.

2.2.1 CARE-S. Baur et al. (2005) helped create the Computer Aided Rehabilitation of Sewer Networks (CARE-S) in Europe which includes software and methods that enable engineers of sanitary sewer projects to establish and maintain effective management of their systems by rehabilitating the right sewers at the correct times. CARE-S uses multi-criteria methodologies to provide three types of decision support: developing a long-term rehabilitation strategy; selecting cost-effective rehabilitation projects; and choosing the most economical rehabilitation method. Although most of the model is used for planning when and what to remediate, part of the model is devoted to determine how to rehabilitate through the use of the balancing and ranking procedure (Strassert, 2000). The rehabilitation database includes more than 40 technologies used for repair, rehabilitation, and replacement of sewer pipes (Baur et al., 2003).

The CARE-S software consists of two main screens. The first, where the pre-selection of suitable technologies is carried out, provides information on the rehabilitation project: including pipe characteristics; failure specification; and description of the environment. The second screen identifies the remaining rehabilitation technologies with their advantages and disadvantages and the ranking process is carried out. The information for each rehabilitation technology and the project specific data required to rank the technologies is shown in Tables 2-6, 2-7, and 2-8 as they relate to applicability, technology performance, and environmental impact, respectively (Baur et al., 2003).

Table 2-6. Applicability Information on Technologies and Project Description in CARE-S

Technology Information	Project Description
Diameter (Minimum and Maximum)	Diameter (Before and After Rehabilitation)
Shape (Circular or Non-circular, Man or Non-man Entry)	Shape (Circular, Egg-shaped or Other)
Asset Type (Sewer, Manhole or Connection)	Sewer, Manhole or Service Connection
Static Function (Structural or Sealing)	Load Bearing Capacity Required (Yes/No)
Material of Current Asset	Material
Need to Cut Off Connections	Number of Service Connections
Below Groundwater Level Admissible	Groundwater Level and Sewer Level
Minimum Temperature	N/A
Suitable Soils	Soil Type
Work Space Required	Available Work Space

Table 2-7. Performance Information on Technologies and Project Description in CARE-S

Technology Information	Project Description
Maximum Length	Length
Working Speed (Length/Day)	Time Constraints (Maximum Days)
Material of New Asset	Material
Diameter (Same, Reduced or Increased)	New Diameter
Hydraulic Performance After Rehabilitation	New Diameter, Slope, and Roughness
Digging Needs (Surface Damage, Pits or Trench)	Flora to be Protected and Traffic Load
Processing though Manhole?	Available Work Space
Need of Cleansing	N/A
Digging Need for Reinstating Connections	Number of Service Connections
Possibility of Work Interruption	N/A
Excess Ground Permeability During Grouting	Sensitive to Groundwater Quality
Requires Man-entry	N/A
Straight or Curved Link	N/A
Estimated Service Life of Rehabilitated Asset	N/A
Unit Costs and Cost Factors	N/A

Table 2-8. Environmental Impact of Technologies and Project Description in CARE-S

Technology Information	Project Description
Impact on Surrounding Structures	Sensitive Structures Around
Impact on Surrounding Area (None, Low or Grave)	Flora to be Protected
Impact on Groundwater Quality	Sensitive to Groundwater Quality
Noise	Noise a Problem
Dust	Dust a Problem

The output from CARE-S includes a ranking of all applicable methods based on the parameters listed above and the aforementioned balancing and ranking procedure.

2.2.2 Critical Gaps of CARE-S. Critical gaps of CARE-S are the lack of U.S. specific rehabilitation technologies and associated unit costs and cost factors. The tool has been developed in Europe based on European standards, costs, and available technologies and would need to be adapted for the U.S. market. The suite of tools is only available as standalone software and is not available via a Web-based system. The tools only take into account sewers, laterals, and manholes; water mains are not included but they are covered under Computer Aided Rehabilitation of Water Networks (CARE-W), which is described in Section 2.3.5. It was unclear from the literature to what degree individual parameters were evaluated, but the data used in the ranking procedure rely on surveys to determine specific weights of the separate parameters, which would again make it hard to adapt in the U.S. unless similar surveys were undertaken to determine appropriate weighting. Despite these gaps, CARE-S is capable of providing its European users with long-term rehabilitation strategies and methodologies for selecting cost-effective rehabilitation projects and economical rehabilitation methods. As of 2011, the CARE-S combination of models is no longer available for use, but some of the individual modules can still be accessed from their various developers.

2.2.3 Prototype GIS-Based Model. Halfawy et al. (2008) developed a GIS-based decision support system prototype for renewal planning of sewer networks which includes a procedure for selecting the most suitable renewal technology. The prioritization portion of the model includes: grouping of all like sewer assets; to reduce data requirements and expedite planning; modeling of pipe deterioration based on condition assessment data; assessing the risk of failure of sewers; and prioritizing the renewal plans.

Once the prioritization is complete, the model evaluates renewal alternatives based on their applicability to project conditions, relative costs, and benefits. The authors proposed new criteria and built upon previous works cited earlier: Matthews and Allouche (2009); Baur et al. (2003); NRCC (2007); Plenker (2002); Diab and Morand (2001); and Shahab-Eldeen and Moselhi (2001). The renewal alternatives are grouped into four categories: (1) replacement; (2) fully-structural lining; (3) semi-structural lining; and (4) non-structural lining. Table 2-9 outlines the technologies and categories available for selection.

Table 2-9. Technologies Available for Selection

Category	Technologies
Replacement	Semi and Open Cut; Pipe Bursting and Splitting; Pipe Insertion; Pipe Reaming; and Pipe Eating
Fully-Structural Lining	Continuous, Segmental and Discrete Sliplining; Fused and Expanded; Fold-and-Form; Deformed and Reformed; Spiral Wound; Panel Lining; In Situ Formed Pipe; CIPP; and Underground Coating and Lining
Semi-Structural Lining	Continuous and Discrete Sliplining; Fused and Expanded; Fold-and-Form; Deformed and Reformed; Spiral Wound; Panel Lining; In Situ Formed Pipe; CIPP; and Underground Coating and Lining
Non-Structural Lining	CIPP and Underground Coating and Lining

Source: Halfawy and Baker, 2009

The procedure begins by determining which category of methods is most applicable based on: (1) soil type; (2) groundwater level; and (3) the sewer condition index, which ranges from (1-Excellent) to (5-Collapsed). Soil type and groundwater level are used to determine the possibility of soil loss (i.e., low, medium or high). The lower the possibility of soil loss and condition index, the lesser the need for a structural renewal. For example, a segment with a ‘Low’ possibility of soil loss and a low condition index (i.e., 2-Low) would only require a non-structural or semi-structural renewal, whereas a segment with a ‘High’ possibility of soil loss and high condition index (i.e., 4 or 5-High) would require a structural renewal or replacement (Halfawy et al., 2008).

Once the category is determined, the applicability of each method is evaluated based on three primary sets of criteria: technology limitations, site conditions, and environmental factors. Technology limitations evaluated include: (1) sewer type; (2) existing defects; (3) pipe diameter; and (4) material. Some of the site conditions considered include: (1) soil types; (2) groundwater levels; and (3) work area requirements (Halfawy et al., 2008).

After the applicability stage, the costs and benefits of each renewal method are estimated and used to rank the applicable alternatives based on their cost/benefit ratio. The costs include direct and indirect costs, and the benefits are calculated in terms of service life. The costs were compiled from the following six references that were reported using various units (mm and in.), currency (Canadian and U.S. dollars) and years (1999-2002), which required the adjustment to a common unit. The sources studied include: Najafi (2004); Garcia et al. (2002); Zhao and Rajani (2002); Selvakumar et al. (2002); EPA (1999); and Ariaratnam et al. (1999). Figure 2-2 is a sample screen shot from the model showing renewal methods and associated costs for a group of assets in Regina, Canada used to evaluate the tool (Halfawy et al., 2009).

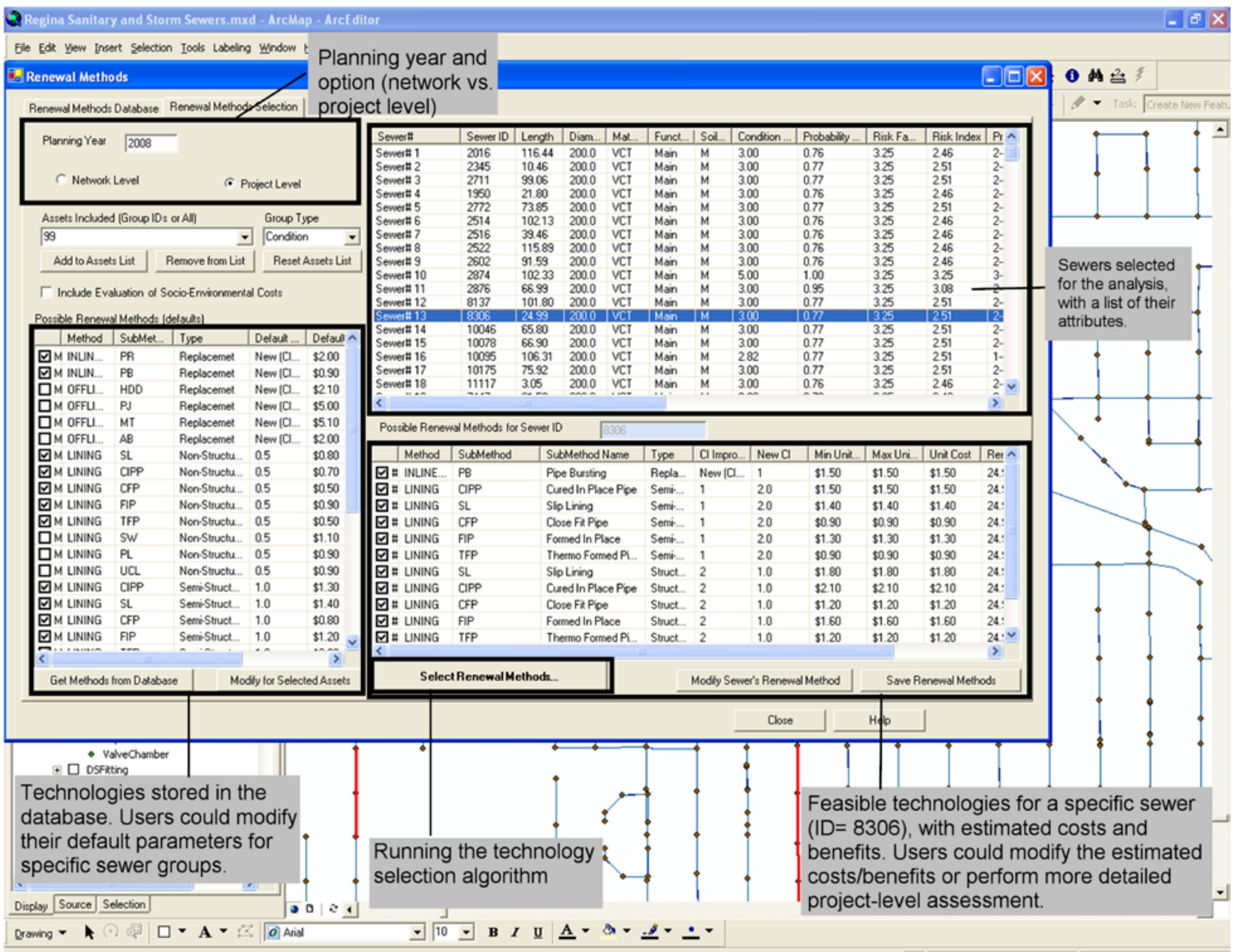


Figure 2-2. Screen Shot of Renewal Methods and Costs

This prototype has the ability to go one step further by performing a multi-objective optimization of the renewal plan for a group of assets using a genetic algorithm which is designed to minimize: the average condition of the network; the average risk of the network; and total life-cycle cost.

2.2.4 Critical Gaps of Halfawy et al. Model. Critical gaps of the Halfawy et al. (2008) model include the lack of U.S. specific technologies and cost factors, which is an easier transition than with CARE-S, being that the tool was developed in Canada. Canada shares many of the same vendors and contractors as the U.S. and some of the cost data in the model were taken from U.S. sources. The software has not been fully developed as of 2010 and has yet to be released for public use. One other gap noted is the use of structural conditions only in the method selection process and not the inclusion of hydraulic capacity, which is a future direction of the researchers. In light of these gaps, when the prototype is fully-developed, it will be capable of evaluating multiple segments and selecting the most cost-effective renewal solution based on pipe defect data, technology applicability, and life cycle costs.

2.2.5 Summary of Wastewater Specific Models. Of the 11 models described above, only one (i.e., Halfawy et al., 2008) includes each of these critical components: ability to process condition assessment and defect data; an extensive (i.e., many commonly used technologies and their associated technical parameters) method database; performs a technical evaluation of the project conditions and characteristics; performs a costs analysis; and performs a final method ranking. Table 2-10 provides a summary of the wastewater specific models described above and their associated capabilities.

Table 2-10. Summary of Wastewater Models

Models, Year	Defect Data	Extensive Database	Technical Evaluation	Cost Analysis	Method Ranking
Duggan and Doherty, 1995	No	No	Yes	Yes	Yes
Bielecki and Stein, 1997	No	No	Yes	Yes	Yes
McKim, 1997	No	No	Yes	No	No
Abraham et al., 1998	No	No	Yes	Yes	Yes
Shahab-Eldeen and Moselhi, 2001	Yes	No	Yes	No	No
Diab and Morand, 2001	No	Yes	Yes	No	No
Plenker, 2002	No	No	Yes	Yes	Yes
Baur et al., 2003	No	Yes	Yes	Yes	Yes
Bairaktaris et al., 2007	Yes	No	Yes	Yes	Yes
Schroeder et al., 2008	Yes	No	Yes	No	No
Halfawy et al., 2008	Yes	Yes	Yes	Yes	Yes

2.3 Water Specific Guidelines and Models

As noted earlier, there are very few decision support models for the selection of methods for wastewater collection systems and yet there were even fewer documented for the selection of methods for water distribution systems. There are, however, several models in the literature that attempt to prioritize and schedule water mains for renewal. Models such as KANEW and PARMS (Burn et al., 2003) provide methods and software for predicting deteriorating pipeline condition, quantifying budgetary level costs, and giving utilities the tools to develop long-term pipe rehabilitation and replacement strategies (Deb et al., 1998). There are models capable of scheduling individual water mains for replacement only, such as the Mains Replacement Prioritization (MRP) tool by the GL Group and Individual – Water Main Renewal Planner (I-WARP), but neither model considers other options such as rehabilitation or repair (Nafi and Kleiner, 2010). One tool capable of evaluating multiple design alternatives is the Darwin Design Module, which works inside of WaterCAD by Bentley, although it does not consider specific installation or replacement technologies. A review of many of the tools being used for scheduling of optimal pipeline replacement can be found in Agbenowsi (2000).

2.3.1 M-PRAWDS. Kleiner et al. (2001) developed a multistage procedure for identifying an optimal rehabilitation strategy for water distribution networks. The model includes pipe relining, replacement with the same diameter, and replacement with a larger diameter as the three options for remediation. The objective of the proposed approach is to minimize the total discounted costs associated with rehabilitation and breakage repair of all of the pipes in the system. Depending on the structural properties of a pipe and costs of remedial action, the program calculates a minimum cost replacement timing variable, which determines when and how to remediate a pipe segment. The inputs for the proposed model include the pipe characteristics listed in Table 2-11.

Table 2-11. Pipe Characteristic Inputs in M-PRAWDS

Pipe Characteristics
Flow (L/s)
Pipe Diameter (in.)
Length (m)
Hazen-Williams 'C'
Installation year
Elevation (m)

The results of the model include the type of action required and the year in which the action should take place. The model is able to consider the deterioration over time of structural integrity and hydraulic capacity of the pipes in the water distribution network using a deterioration model. The model is also capable of considering the economics and performance of the entire network while regarding each pipe as separate entities.

2.3.2 Critical Gaps of M-PRAWDS. The primary critical gap of this model is that it does not include multiple rehabilitation and replacement options and their specific application and costs. The model makes assumptions as to the life cycle of relining actions, which may vary greatly, and it does not allow for the inclusion of method specific data such as cost, applicability, and design life. It is not clear if the model has ever been fully validated, as the computing resources required to run the program were considered excessive in 2001 for this type of model and no recent references were located discussing significant updates or developments. The model was suitable for relatively small distribution systems with the computation techniques and equipment available at the time of development, but it was not clear how the model was implemented and whether it could be used easily by utilities. Currently, research is ongoing to scale up the optimization elements of the system for use on a large network. As of 2011, some elements of M-PRAWDS have been incorporated into Distribution – Water Main Renewal Planner (D-WARP), which is available free for download through the NRCC Web site.

2.3.3 Comprehensive Decision Support System. Deb et al. (2002) developed a comprehensive decision support system (CDSS) consisting of a Technology Selection Module (TSM) and a Cost Module (CM) for the selection of appropriate renewal methods for water distribution mains less than 24 in. The TSM makes technology recommendations based on the problem associated with the pipe, pipe characteristics, and site conditions. The TSM considers five rehabilitation and six replacement technologies shown in Table 2-12 (Khambhammettu, 2002).

Table 2-12. Technologies Contained in TSM

Rehabilitation Technologies	Replacement Technologies
Cement Mortar Lining	Open Trench
Epoxy Resin Lining	Narrow Trench
Close-Fit Sliplining	Pipe Bursting
Cured-in-Place Pipe	Conventional Sliplining
Cathodic Protection	Horizontal Directional Drilling
	Jack and Bore

The inputs for the TSM include the problem type (Table 2-13), and pipe and site characteristics (Table 2-14). Once a preliminary selection takes place to determine which of the 11 technologies listed in Table 2-12 are applicable, the CM is used to perform a cost analysis of each of the viable options.

Table 2-13. Problem Types in TSM

Problem Type	Renewal Options
Structural	Replace Pipe or Insert Structural Liner
Hydraulic	Replace with Larger Pipe or Add Additional Parallel Pipe
Joint Leakage	Insert Semi-Structural Liner
Water Quality	Insert Non-Structural Liner or Apply Cathodic Protection

Table 2-14. Pipe and Site Characteristic Inputs in TSM

Pipe Characteristic	Site Characteristic
Pipe Material (Existing and New)	Soil Conditions
Pipe Diameter (Existing and New)	Presence of Hydrocarbons
Diameter Change of Pipe Length	Site Conditions
Renewal Length	Water Table
Number of Bends	Major Obstructions at the Site
Number of Service Connections	Workspace
Service Connections to be Replaced	Water pH
Number of Isolation Valves	
Isolation Valves to be Replaced	

The CM contains more than 15 worksheets for determining the cost associated with a particular technology selected using the parameters presented above. The input worksheet stores all of the values entered by the user during the TSM process and the user will fill in the unit cost worksheet for equipment, pipe material, and labor. Other worksheets include costs for mobilization and demobilization; site preparation; permit fees; flushing; cleaning; bypass; traffic control; excavation; main and service reconnection; site restoration; pressure testing; disinfection; and the total cost associated with each technology based on the previous worksheets.

2.3.4 Critical Gaps of CDSS. The critical gaps of the model developed by Deb et al. (2002) include the fact that the framework was not flexible enough to accommodate newer technologies as they become available since it was built as a stand-alone system. This creates the need for the developers to stay in constant touch with the industry to be able to adjust the constraints of the system in accordance with technological advances (Khambhammettu, 2002). No newer references were found in the literature to suggest that this model has been used widely or developed any further; however, this model takes into account all of the necessary components to produce a CDSS for water main rehabilitation technology selection and cost comparison.

2.3.5 CARE-W. CARE-W is a suite of decision support tools developed in Europe (not yet commercially available) but the tools have been applied in Las Vegas, NV; Boston, MA; and Aquarion, CT, on a trial basis (Vanrenterghem-Raven, 2008). CARE-W is comprised of five primary components, which include independent tools developed by research partners relating to the optimization of water distribution renewal planning that are connected to a shared database module (Saegrov, 2005).
The first component uses performance indicators (PIs) to estimate the condition of a water system. This is done by comparing the network at the present time and in the future versus as many as 49 performance indicators relating to (1) water resources; (2) physical; (3) operational; (4) quality of service; and (5) financial (Baptista and Alegre, 2001). The second component includes five separate tools that predict failures on a group of pipes based on statistical, probabilistic or physical means. The tools include the: (1) Markov model, based on Asset-map1 (Malandain et al., 1999); (2) Poisson model, based on Asset-map2 (Malandain et al., 1999); (3) Proportional Hazard Model (PHM), based on Failnet-Stat (Le Gat and Eisenbeis, 2000); (4) UTILNETS (Hadzilacos et al., 2000); and (5) Non-Homogeneous Poisson Process (NHPP) model, based on Winroc (Rostum, 2000; Eisenbeis et al., 2002). Another model similar to the NHPP model developed here is the I-WARP model developed through the Water Research Foundation (WaterRF) and NRCC which considers dynamic factors in addition to static factors (Kleiner and Rajani, 2010).

The third component includes three separate tools that can assess the hydraulic reliability of a pipe or a group of pipes. The tools include: (1) Aquarel, works with EPANET (Rostum et al., 2000); (2) Failnet-Reliab (Le Gat and Eisenbeis, 2000); and (3) RelNet, works with ODULA, which is based on EPANET (Tuhovak et al., 2001; Eisenbeis et al., 2002). The fourth component is the annual rehabilitation planning tool (ARP) which is used for the prioritization of rehabilitation projects on a yearly basis in the short term and over the long term, based on the impact of the condition of the pipe (Le Gauffre et al., 2007). The fifth and final component includes three separate tools used for developing realistic scenarios, simulating long-term effects, and ranking rehabilitation strategies. The tools include: (1) Scenario Writer; (2) Rehabilitation Strategy Manager, based on the KANEW model, which is no longer available for use as of 2011; and (3) Rehabilitation Strategy Evaluator, which takes output from (1) and (2) (Herz and Kropp, 2002).

2.3.6 Critical Gaps of CARE-W. The critical gaps of CARE-W are the lack of replacement and rehabilitation technology information. The tool is not capable of determining whether replacement or rehabilitation is the appropriate action for a given situation in terms of technology applicability and direct and indirect costs. Although this tool was developed in Europe, it has been applied to U.S. utilities for water rehabilitation strategy and planning, but not for technology selection. Similarly to CARE-S, the CARE-W combination of modules is no longer available for use, but some of the individual modules can still be accessed from their various developers.

2.3.7 Ammar et al. Model. Ammar et al. (2010) proposed the first known model capable of selecting and ranking methods solely for the rehabilitation of water mains. The model focuses on the life cycle cost analysis (LCCA) of each rehabilitation method to determine which option is the most economically effective. Table 2-15 summarizes the components, inputs, and outputs of the model.

Table 2-15. Components of Ammar et al. Model

Component	Details
Rehabilitation Options	Repair, Renovation, and Replacement
Rehabilitation Frequency	Breakage Data and Deterioration Curves
Cost Parameters	Rehabilitation and O&M Costs
Model Parameters	Discount Rate, etc.
Evaluation and Ranking	Fuzzy-based LCCA Model

The model incorporates the most commonly used technologies in the industry capable of repairing, rehabilitating, and replacing water mains. Table 2-16 outlines the technologies considered.

Table 2-16. Technologies Considered in Ammar et al. Model

Category	Method
Repair	Sleeve Spot Repair
Repair	Open Cut Spot Repair
Rehabilitation	Cement/Epoxy Lining
Rehabilitation	Sliplining
Rehabilitation	CIPP
Replacement	Pipe Bursting
Replacement	Open Cut
Replacement	HDD
Replacement	Microtunneling

2.3.8 Critical Gaps of Ammar et al. Model. The critical gaps of the Ammar model include the lack of validation and testing by industry users. The model has not been made available for public use and will not have proper validation until it has been tried in real world situations. The model does not take into account parameters such as diameter and depth because the authors concluded that those parameters did not affect the ranking of the methods. This conclusion is difficult to accept because even though each simulation provided similar ranking results despite various diameters, those parameters would always affect the total cost, which should be taken into account in a cost analysis.

2.3.9 AWWA M28 Flowcharts. The American Water Works Association (AWWA) M28 Manual contains three flowcharts capable of selecting rehabilitation techniques for resolving structural, water quality or flow, pressure, and leakage problems as shown in Figures 2-3, 2-4, and 2-5 (AWWA, 2001). All three flowcharts are reprinted from M28 – Rehabilitation of Water Mains by permission (Copyright © 2001, AWWA). The latest edition of the manual was published in 2001, but is currently being updated.

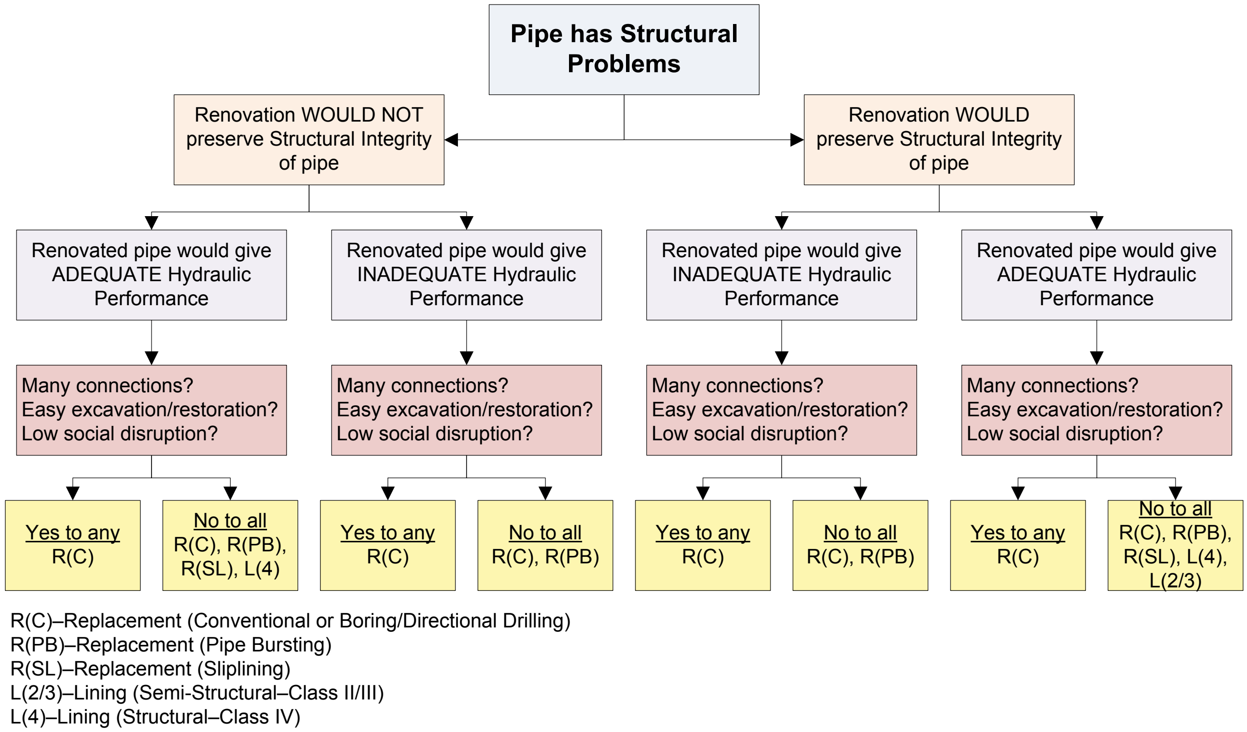


Figure 2-3. Selection of Techniques to Resolve Structural Problems (AWWA, 2001)

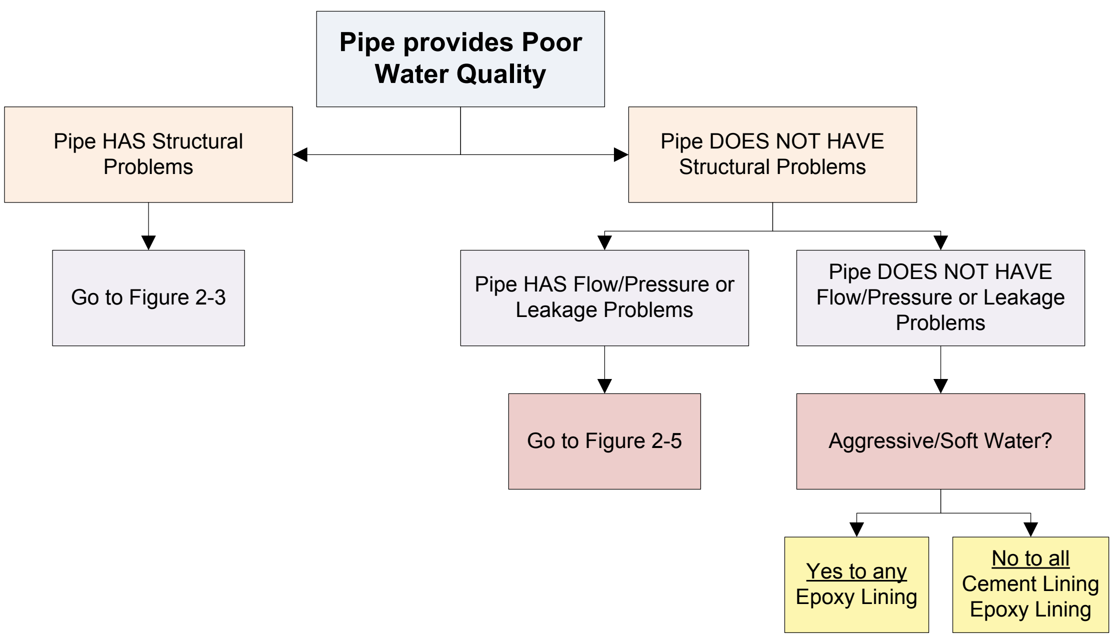


Figure 2-4. Selection of Techniques to Resolve Water Quality Problems (AWWA, 2001)

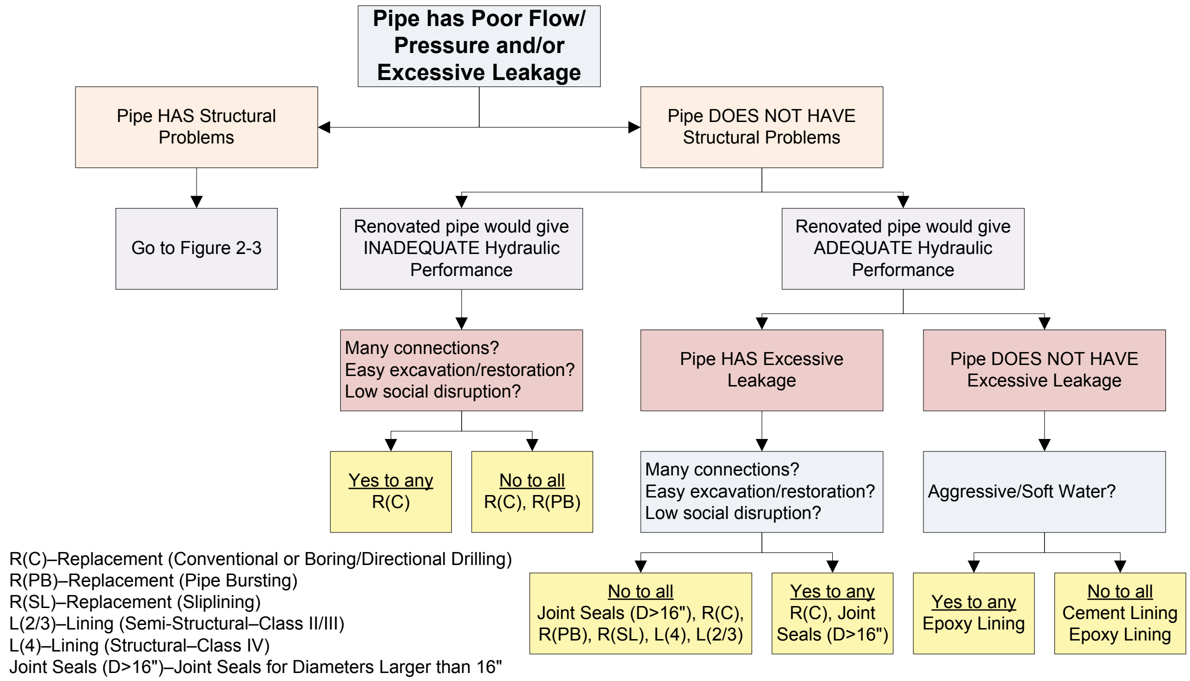


Figure 2-5. Selection of Techniques to Resolve Flow and Leakage Problems (AWWA, 2001)

2.3.10 Critical Gaps of AWWA Flowcharts. The critical gaps of the AWWA flowcharts include the lack of condition assessment defect data; absence of an extensive method database; lack of a cost analysis; and the flowcharts do not rank the appropriate methods. Also, the flowcharts are nearly 10 years old and several new technologies have come into the market since 2001, which warrant inclusion in the technical evaluation and results.

2.3.11 Summary of Water Specific Models. Of the five models described above, only one, Ammar et al., addresses each of the critical components: ability to process condition assessment and defect data; contains an extensive (i.e., many commonly used technologies and their associated technical parameters) method database; performs a technical evaluation of the project conditions and characteristics; performs a costs analysis; and performs a final method ranking. Currently, a research project is underway to develop a simple and practical tool that will determine whether cast iron mains warrant renovation or rehabilitation (WaterRF, 2010). Another recently proposed model bases the method selection decision on the cost of the water system performing inadequately in the form of lost water versus the costs of renewal (De Marinis et al., 2008). Table 2-17 provides a summary of the water specific models described above and their associated capabilities.

Table 2-17. Summary of Water Models

Models, Year	Defect Data	Extensive Database	Technical Evaluation	Cost Analysis	Method Ranking
M-PRAWDS, 2001	Yes	No	Yes	Yes	Yes
Deb et al., 2002	No	Yes	Yes	Yes	Yes
CARE-W, 2005	Yes	No	Yes	Yes	No
Ammar et al., 2010	Yes	Yes	Yes	Yes	Yes
AWWA, 2001	No	No	Yes	No	No

3.0: CASE STUDIES OF RENEWAL DECISION-MAKING APPROACHES

The purpose of the case studies outlined below was to gain an understanding of how utilities make the decision of which technology to use when replacing or rehabilitating existing water or wastewater pipes. Eight utilities/cities were visited to obtain information about the current models and methodologies being used for method selection throughout the nation. Each case history included a preliminary review via phone and e-mail to determine the process each city uses, (whether it was software tools, design manuals, use of hired consultants or a combination of them all). Each preliminary discussion was followed by a site visit where decision-making personnel were interviewed and decision-making data were obtained. One day meetings were set-up with decision makers in Atlanta; Columbus; Dallas; Indianapolis; Miami; New York City; Las Vegas; and Los Angeles. Five of the eight contacts were existing TTC Industry Advisory Board (IAB) members and the other three contacts were established through existing industry contacts. The primary contacts are provided in Table 3-1 with their area of interest (i.e., W-water or WW-wastewater) and the location of each utility (blue stars) is shown in Figure 3-1.

Table 3-1. Summary of Case Study Contacts

Contacts	Job Title	City/County	Area
Michael Hines	Senior Program Manager	Dallas, TX	W/WW
James Gross	Assistant Asset Manager	Columbus, OH	W/WW
John Morgan	Assistant Administrator, Tunneling	Indianapolis, IN	WW
Charles Scott	Engineering Project Manager, Water	Las Vegas, NV	W
Keith Hanks	Senior Engineer, Wastewater	Los Angeles, CA	WW
Raymond Hutchinson	Consultant, Clean Water Atlanta	Atlanta, GA	WW
Dino Ng	Assistant Commissioner, Infrastructure	New York, NY	W/WW
Rod Lovett	Chief, Wastewater Collection	Miami, FL	WW

In addition to eight utilities visited and documented below, another 27 large utilities were contacted to determine if other unique methodologies were being used. Of those 27, nine additional utilities (red stars) responded and commented on their method selection approach and the remaining 18 utilities (green stars) were unresponsive. A summary of the nine responsive utilities is shown in Table 3-2.

Table 3-2. Summary of Additional Study Contacts

Contacts	City/County	Area
Jack Neely	San Diego County, CA	W
Greg Ballard	Nashville, TN	WW
Blaine Robinson/Darlene Helm	Phoenix. AZ	W/WW
Irene McSweeney	Boston, MA	W/WW
Nancy Musinski	Albuquerque Bernalillo County, NM	W/WW
Jonathan Chow	San Francisco, CA	W
Ken Chua	Edmonton, AB	WW
Richard Nettleton	Virginia Beach, VA	W/WW
Roy Brander	Calgary, AB	W/WW

Figure 3-1. Locations of Case Study Visits (blue stars), Additional Utilities (red stars) and Non-Responsive Utilities (green stars)

The interaction with each city was used to obtain case study data that would accomplish the following two objectives: (1) determine what, if any, models each city uses and categorize and document the models in a similar manner to the ones described in the literature review, and (2) where models were not used, to determine the process the city uses to make their method selection decision.

Objective 1 helped to determine what models are being used currently and to what degree of success. This was similar to the information obtained from the literature review except the cities were able to provide the model's strengths and limitations.

Objective 2 provided the key variables and parameters that cities are using to make their method selection decision in the way an expert system would perform the process. These variables and procedures are documented below and will be compared to the variables and procedures of the current models identified in the literature review and objective 1 to identify the critical gaps of each system in Section 4.

3.1 Case Study #1: City of Dallas Water Utilities

A meeting with Mr. Michael Hines, the Capital Improvement Project (CIP) Program Manager for Dallas Water Utilities (DWU); members of both the wastewater and water groups within DWU; and an Engineering Consultant was conducted on April 12, 2010 to determine the City's methodology for determining how to rehabilitate and/or replace existing wastewater and water utilities. Mr. Hines has worked with DWU for more than 25 years as a design engineer, project manager, and CIP program manager. The other members of the DWU team included Engineering Services Program Manager Chad

Kopecki, wastewater and water project managers Shahrzad Tavana and Johnny Partain, respectively, as well as a field operations manager.

3.1.1 Introduction. Dallas is located in the northeast area of Texas and extends into five counties. The city's population is around 1.3 million making it the third largest city in Texas and the ninth largest city in the U.S. Dallas has a system of more than 4,300 miles of sanitary sewer and 5,000 miles of water distribution mains. The city performs around $100 million in water and wastewater capital improvement main replacement projects each year with around $1 million being budgeted for CIPP projects and another $165,000 for fold-and-form projects. Dallas's Wastewater Collection Division (WCD) reported they have performed around 5,700 linear feet (lf) of CIPP rehabilitation and 4,500 lf of fold-and-form over the past 12 months.

3.1.2 Renewal Program. Dallas's wastewater and water utility renewal programs are primarily driven by available funding and the associated prioritization of the most crucial needs within their systems. Dallas is not under a consent decree (CD) with EPA, but it does have a voluntary Sanitary Sewer Overflow (SSO) Initiative with the Texas Commission on Environmental Quality (TCEQ). Capital improvement projects are intended to address aging wastewater pipes on the verge of structural failure as well as to remove ground water infiltration from the system. Some of the site-specific rehabilitation challenges for the City of Dallas include: (1) the design engineer making an improper trenchless method selection; (2) wastewater bypass pumping on mains 24 in. and larger; and (3) properly indentifying the live laterals in older commercial areas that have multiple laterals on the main to be rehabilitated.

DWU utilizes an in-house design department, in conjunction with its Pipeline Design Manual, as well as multiple external engineering consultants to recommend one or more technologies for rehabilitating and replacing existing wastewater pipes and water distribution mains as part of their CIP. Even though Dallas does not have a fully automated process for replacement and rehabilitation technology decisions, the wastewater group utilizes a tool, developed by a consultant (Montgomery Watson Harza [MWH]), that determines the cost-effectiveness of the three commonly used technologies (i.e., Open Cut, Spot Repairs or CIPP). Dallas has used a limited number of technologies for both wastewater and water distribution replacement and rehabilitation projects, but would welcome a tool that incorporated more technologies into cost estimation, therefore identifying more alternatives.

Dallas has typically used open cut (97%) for the replacement of wastewater pipes, both small and large diameter, which need addressing due to the cost-effectiveness of the technology in the region. Replacement pipe materials are either polyvinyl chloride (PVC) or Fiberglass for larger diameters pipes and open cut replacement is used for pipes as deep as 20 ft (typically 15 ft or less). The two other technologies commonly used for the rehabilitation of wastewater pipes are CIPP for both large and small diameters as well as fold-and-form for diameters up to 15 in. CIPP is being used more and more as it has become cost-effective.

In addition to these commonly budgeted technologies, other technologies have been used in the past when unique situations have arisen. Spiral wound lining was used in the early 1990s on a horseshoe shaped pipe. The shape of the pipe made using CIPP difficult and raised concerns about excessive folding of the CIPP liner. Sliplining has been used on large diameter pipes in the past where capacity was not an issue including the sliplining of a 60 in. concrete pipe with 52 in. fiberglass pipe and sliplining a 48 in. concrete pipe with 42 in. PVC. Pipe bursting using PVC has been used on small diameter wastewater pipes up to 24 in., where additional capacity was required and open cut was deemed too difficult due to access.

Dallas would like to incorporate all of the technologies that are included in Section 4.9 of its Pipeline Design Manual into its cost estimation tool as well as other technologies which may be applicable and technically viable to address their needs in addition to the three mentioned earlier. The Pipeline Design

Manual outlines the technical capabilities of four rehabilitation methods (pipe bursting, sliplining, CIPP, and fold-and-form) in terms of their technical envelope including applicability, diameter, length, pipe materials, and special considerations. A summary of the technologies typically being used by DWU is shown in Table 3-3.

Dallas uses open cut for the replacement on water pipes needing remediation, which is determined by their break history index about 99% of the time. Water pipes are broken down into three primary size categories: small diameter, up to 12 in.; pipes in the central business district (CBD) or airport class, 12 to 16 in.; and large diameter pipes, greater than 24 in. Replacement pipes are different for each category: PVC being used for small diameter pipes; ductile iron for CBD and airport class pipes; and concrete for large diameter pipes. In addition to open cut, other technologies have been used for water main rehabilitation for pilot projects such as CIPP and fold-and-form, which were used when access limited the use of open cut. In addition, other technologies have been used on rare occasions as pilot projects to demonstrate new technologies and materials. Sliplining using a 30 in. high density polyethylene (HDPE) pipe, which would typically be bid against fusible PVC, was demonstrated on a 36 in. cast iron section, but it initially leaked at all tie-in locations. A demonstration of an epoxy coating was performed at a location where open cut was impossible and capacity was not an issue on a section which did not have a break history. Another demonstration utilizing a hose liner was deemed unsuccessful. A summary of the technologies typically being used by the City of Dallas for water main rehabilitation and replacement is shown in Table 3-4.

Table 3-3. Summary of Wastewater Technologies Used

Wastewater Technologies
Open Cut (97%)
CIPP
Fold-and-Form (up to 15 in.)
Point Repairs (up to 18 in.)

Table 3-4. Summary of Water Technologies Used

Water Main Technologies
Open Cut (99%)
CIPP
Sliplining

3.1.3 Technology Selection Methodology. The Dallas technology selection process comes down to selecting the most cost-effective solution for the pipes in most need of remediation based on condition assessment analysis. In addition to being cost-effective, the remediation action must also be technically applicable. Typically, the technology selection process will follow these three stages: (1) condition assessment; (2) technical evaluation; and (3) cost-effectiveness evaluation. The decision support tool estimates the cost of three primary technologies (open cut replacement of the full line or by spot repair and CIPP) and also provides recommendations for rehabilitation and inspection. The tool was developed by an outside consultant (MWH) while they were reviewing the current process being used by the City of Dallas to collect and evaluate CCTV data.

Dallas hired MWH to develop a simplified renewal risk rating based on the condition assessment and associated defect codes and consequence of failure scores which were established utilizing a GIS analysis to assess the potential impact of the structural failure of each pipe. Defect codes are based on the PACP codes developed by NASSCO and are broken down into five categories as outlined in Table 3-5.

Table 3-5. PACP Defect Grade Categories

Condition	Description
Level 5	Defects requiring immediate attention
Level 4	Defects that will become Grade 5 soon
Level 3	Moderate defects that will continue to deteriorate
Level 2	Defects that have not begun to deteriorate
Level 1	Minor or no defects

From these five defect code categories, a quick structural rating (QSR) made up of a four digit score was developed. The score is defined as:

First digit: The highest condition grade occurring along the pipe
Second digit: The number of occurrences of the highest condition grade
Third digit: The next highest condition grade occurring along the pipe
Fourth digit: The number of occurrences of the next highest condition grade

The QSR index is incorporated into the decision support tool described below to help determine whether any remedial action or future inspection is needed. If the QSR is greater than 4000, meaning that there is at least one Level 4 defect along the pipe, the user will be recommended to continue the evaluation process. However, if the highest condition defect is Level 3 or lower, the user will be instructed to review it at the next inspection cycle. There could be cases where a poor conditioned pipe may require a spot repair first followed by full segment liner. The logic for the decision-making process is presented in the flowchart in Figure 3-2.

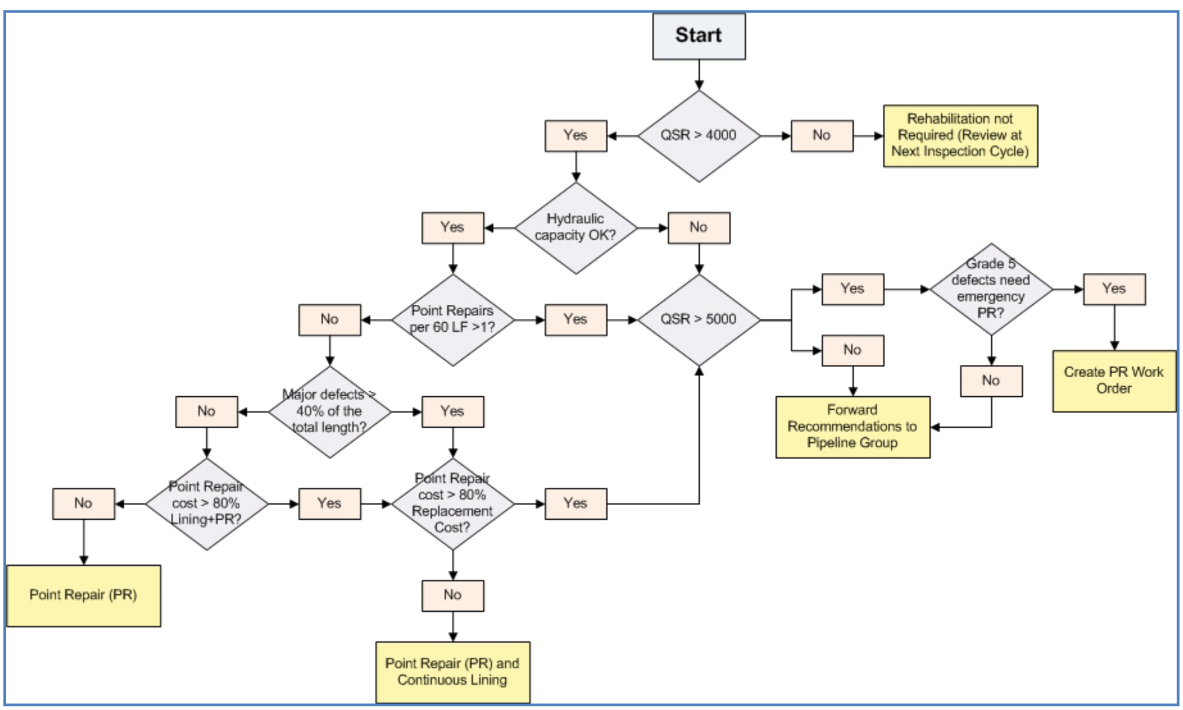


Figure 3-2. Decision-Making Logic for Wastewater Rehabilitation

Once a pipe segment is considered to need remediation, many parameters must be considered to determine what technologies may or may not be applicable. These parameters include: (A) hydraulic capacity; (B) existing alignment; (C) pipe length; (D) diameter; (E) depth; (F) hazardous conditions; and (G) host pipe access and location and are described below.

When hydraulic capacity is limited, any technology that would reduce the capacity even more is not usually considered and open cut or pipe bursting would be considered as viable options. Another parameter lending itself to open cut replacement is misalignments. Sags and multiple bends can limit the cost-effectiveness of pipe bursting and sliplining, which would require more pits, as well as CIPP, where bends and sags can cause problems with robotic lateral reinstatements.

The length of the host pipe and diameter can be limiting factors for some technologies depending on the specific capabilities of a technology. Also, longer lengths of pipes typically reduce unit costs by reducing the mobilization cost for a particular technology.

Deep pipes, usually 20 ft or deeper, would eliminate open cut and pipe bursting as viable options due to the difficulty of access as would some soil conditions which are harder to dig and shore up. Another parameter that would typically restrict excavation and therefore open cut construction is pipes located in contaminated areas. The areas would create hazardous work zones and lend themselves to technologies not requiring much excavation. Also, high traffic areas or narrowed easements (less than 10 ft) would promote the use of trenchless methods. There are two other specific parameters that typically eliminate pipe bursting from further consideration. Pipe sections which are encased or embedded in concrete can be difficult to pipe burst. In addition pipes in close proximity to other utilities make it difficult to replace the pipe via pipe bursting due to the destructive nature of the replacement method.

One specific factor leading to the use of less disruptive or trenchless technologies, even when open cut is considered to be a more cost-effective solution, is a city policy that discourages not making pavement cuts into streets five years old or less. This policy affects both wastewater and water rehabilitation projects and guides the designers to specify technologies such as CIPP.

Dallas maintains a database of cost for commonly specified methods which includes a unit cost per linear foot for a range of diameters from 6 to 78 in. Also included in the database is an additive factor for amount of pavement to be restored. Pavement restoration due to the digging of access pits is one of the primary cost factors for technologies like open cut and pipe bursting. Other parameters included in the unit costs are materials, time, and labor. Dallas's method selection process is summarized in Table 3-6.

Table 3-6. Summary of Dallas's Method Selection Parameters

Condition Assessment
CCTV Surveys and PACP Codes are used for Pipe Prioritization
Technical Evaluation
Hydraulic Capacity, Existing Alignment, Pipe Length, Diameter, Depth, and Access
Cost-Effectiveness Evaluation
Pavement Restoration, Material, Time and Labor, and Access Pits

One way that the wastewater and water groups work together is by informing each other of their projects so that the other group is given the chance to inspect their pipes in that area. When the pavement is being cut into for a wastewater or water replacement project, a condition assessment of the other main will be made as well to see if it needs to be addressed. This practice reduces the cost of pavement restoration for the city and disruption to the community.

The tool, shown in Figure 3-3, begins by inquiring about the QSR. A rating of less than 4000 means that the pipe has a least one defect along the pipe segment of a 4 or 5, which signifies a critical condition. For the example below, an 8 in. pipe less than 10 ft deep had only one 10 ft defect along its 500 ft length. The tool estimated the cost to replace the pipe with open cut to be $69,500 based on the unit cost of $139/lf for 8 in. open cut less than 10 ft deep. The unit cost values are stored in a database that works in conjunction with the decision support tool. The cost of rehabilitating the line with CIPP would be around $60,000 based on a unit cost of $120/lf. The cost of replacing the 10 ft defected section with an open cut spot repair would be around $17,200 based on $1,720/lf of defect, making it much more cost-effective when compared to full line remediation actions. However, the tool recommends not to rehabilitate the pipe due to its less critical nature based on the QSR and to inspect it again on the next inspection cycle. The unit costs for CIPP and fold-and-form are based on a 3 year price agreement when the appropriate project conditions apply such as length, diameter, accessibility, and capacity.

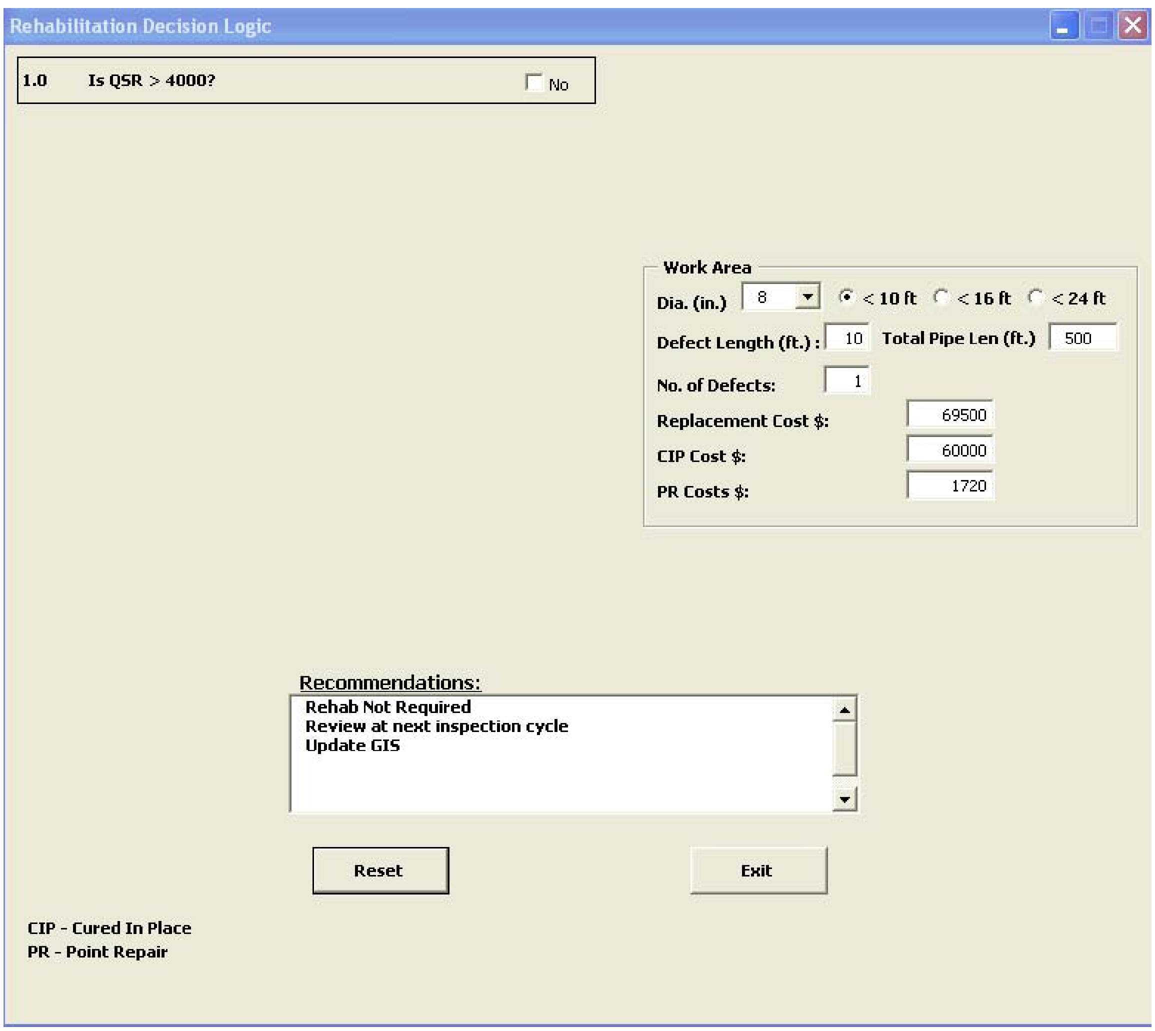


Figure 3-3. Screenshot of Dallas' DSS Tool

Dallas also addresses its laterals and manholes, but the selection process is currently very limited. The city maintains the sewer laterals from the sewer main to the property line cleanout, if one exists. Typically, the sewer laterals are replaced by open cut up to the property line with a cleanout added, if it does not already exist, at the time of a main line repair. In addition to open cut, a pilot project using CIPP for lateral rehabilitation after the main had been rehabilitated using CIPP was done to eliminate I/I and root intrusions at the lateral location. Manholes are typically rehabilitated with epoxy coating technologies, but recently cementitious coatings have been allowed on a trial basis.

3.1.4 Conclusions and User Needs. Mr. Hines indicated that Dallas would be interested in an automated decision support tool or guide that could incorporate each of the rehabilitation (and installation) methods outlined in its design manual and other rehabilitation alternatives for wastewater and water pipes and estimation of their associated regional costs. They would like to tie such a tool to a sustainable construction rating. The tool would need to be user friendly and able to import currently tracked bid prices. It was mentioned that the tool should include a section of pros and cons for each technology and what to watch for and lessons learned from past projects in the form of technology case histories, including reference material that the user could use to obtain more information regarding the use of a technology.

Contact: Michael Hines, (214) 948-4242, charles.hines@dallascityhall.com

3.2 Case Study #2: City of Columbus, Department of Public Utilities

Meetings with Mr. James Gross, the Assistant Asset Manager for Department of Public Utilities (DPU); the Asset Manager, Kevin Campanella; members of both the wastewater and water groups, including engineers and project mangers; and three different consultant firms took place on April 21, 2010. The purpose of the meetings was to discuss two separate prioritization models being developed by the engineering consultants and also discuss the typical selection process for determining how to rehabilitate and/or replace existing water and wastewater pipelines. Mr. Gross has worked for the DPU for over 10 years, primarily in the wastewater division, and he has been closely involved in the design and specification of technologies for the replacement and rehabilitation of wastewater pipes.

3.2.1 Introduction. Columbus is the largest city in Ohio and is located in the center of the state on the I-70 corridor. It is the county seat of Franklin County although it extends into three counties. The city's population is around 770,000 making it the 16th largest city in the U.S. and fourth largest in the Midwest. Columbus has a system of 6,300 miles of sanitary, combined, and storm sewer and 3,800 miles of waterline. The city's rehabilitation budget fluctuates yearly, but the city maintains an annual $2 million lining contract for wastewater projects.

3.2.2 Renewal Program. Columbus's renewal program is driven primarily by combined sewer overflows (CSOs) and SSOs. The city is currently under a CD with EPA to address wet weather capacity, which is not one of the rehabilitation program drivers. The renewal projects address I/I and structural failures and the ultimate objective of the renewal program is a strategic capital improvement program capable of mitigating risk and providing reliability.

Columbus typically uses in-house designers and outside consultants to recommend how to replace or rehabilitate existing water and wastewater pipes. The city does not have an automated process for technology selection, but it has been in the process of developing automated prioritization models to help initiate rehabilitation projects and to plan the funding of those projects based on condition assessment reports and consequence of failure studies. Columbus does not see the need for an automated decision-making tool due to the fact that (1) CIPP is extremely cost-effective for the rehabilitation of wastewater pipes; and (2) open cut with ductile iron is the cost-effective way they have found to replace water distribution mains in need of improvement.

For wastewater pipes, rehabilitation for small and large diameter sewers is done using CIPP 99% of the time primarily due to its cost-effectiveness versus other technologies in the region. For situations where capacity was a deciding factor and the use of CIPP was deemed to be difficult, sliplining has been used. For pipes that are crushed or broken and can't be lined, full line or spot repair replacement by open cut would be considered. Fold-and-form has not been approved for use by the City of Columbus, but it would be considered for use on small diameter pipes if approved. Pipe bursting has been used privately on lateral replacement projects, but not on capital projects due to its high cost when compared with open cut and the need for entry and exit access pits as well as pits for reconnecting each lateral. For a material and method to be approved for use by the City, a packet must be submitted which includes product documentation, regional utility references in addition to a test project and independent third-party quality assurance (QA) testing. A summary of the technologies typically being used by the City are shown in Table 3-7.

Table 3-7. Summary of Wastewater Technologies Used

Wastewater Technologies
CIPP (99%)
Open Cut (Full line or Spot Repair)

For water mains, the decision to replace or rehabilitate a pipe is determined by two parameters: (1) the number of breaks in the main and (2) the number of leaks along the main. For water mains determined to be in need of remediation, typically the main would be replaced with a ductile iron pipe using open cut construction. When a full length excavation is not feasible due to above ground obstacles or multiple adjacent utilities below ground, other technologies might be considered. The use of CIPP liners is considered viable when there are very few service taps that will need reopening. In addition to CIPP, a clean and mortar line project was recently completed which removed tuberculation that had built up in a pipe and then a cementitious mortar coating was applied. The water group has considered other liners that are capable of reinstating the taps internally for locations where excavation would be very difficult. A summary of the technologies typically being used by the Columbus DPU for water main rehabilitation and replacement is shown in Table 3-8.

Table 3-8. Summary of Water Technologies Used

Water Main Technologies
Open Cut (99%)
Clean and Mortar Line
CIPP and Other Liners

3.2.3 Technology Selection Methodology. Cost is typically the number one deciding factor for Columbus when determining how to rehabilitate or replace existing water and wastewater pipes. The other parameters that have to be considered include: (1) level of service required (capacity); (2) pipe characteristics; (3) access to the pipe; and (4) condition of the pipe. Columbus obtains condition data from CCTV surveys to determine the condition of wastewater pipes. For drinking water mains, main break data, which are available back to 1969, and maintenance history help to determine the structural integrity and water quality surveys are used to assess the condition of water mains. Based on these condition assessments and required level of service studies to determine required flow capacity of wastewater mains and fire flows of water mains, designers can determine which pipes are in need of renovation and to what degree.

Once the factors from above are determined, the cost-effectiveness of a technology can be calculated, based on variables such as material and labor required when using a technology. Other cost parameters include pavement restoration costs (i.e., for open cut repairs or access pits for the reinstatement of laterals) and traffic control costs. Columbus's method selection parameters are summarized in Table 3-9.

Table 3-9. Summary of Columbus's Method Selection Parameters

Level of Service Required
Flow Capacity and Fire Flows
Pipe Characteristics
Length, Diameter, Depth, Material, Old Valves, Sags, and Bends
Access to the Pipe
Above Ground Access for Pits and Manholes
Condition Assessment
CCTV Surveys, Drinking Water Quality, Maintenance History, and Main Break Data
Cost
Technology Unit Costs, Traffic Control, and Restoration Costs

After a technology has been selected, DPU prepares the project plans and specifications on which the contractors will then bid. Columbus has standard specifications for each of the technologies approved by the city and makes changes to those specifications on a project by project basis as needed.

One example of a wastewater rehabilitation project where CIPP was not used can show how some of the selection parameters come into play. The Brewery District is an area that was redeveloping and in the process some of the sewer mains had to be renewed, many of which were relined using CIPP for pipes in the 48 to 60 in. range. However, one 72 in. poured-in-place concrete main called for a different strategy due to the pipe characteristics. Capacity was not an issue for this segment; access was limited, thus ruling out open cut replacement and a major sag created concerns with using CIPP. It was determined that sliplining would be an appropriate method as it would not limit the capacity beyond requirements and it would be able to eliminate the sag. The project was a success and although this is not a typical project, the city's selection process was successful.

Columbus does not typically address laterals due to the fact that the property owner owns them all the way to the main. Columbus rehabilitates manholes, typically with cementitious linings (99%). CIPP liners have been used on rare occasions which required high performance liners due to high groundwater pressure on manholes along rivers and creeks.

3.2.4 Conclusions and User Needs. In Columbus, project cost is the number one determining factor for selecting how to rehabilitate or replace both water and wastewater pipes. The final decision depends on providing the required level of service at the lowest possible life cycle cost. For the City of Columbus that decision is typically CIPP for wastewater pipes and open cut with ductile iron for water mains. Mr. Gross indicated that Columbus would be interested in using a DSS tool for estimating the various cost items for alternatives technologies if more were approved for use by the city, but does not see a need for such a tool with the limited amount of methods currently being used.

Contact: James Gross, (614) 645-6528, jmgross@columbus.gov

3.3 Case Study #3: City of Indianapolis, Department of Public Works

A meeting with Mr. John Morgan, the Assistant Administrator of Tunneling for the City of Indianapolis, was conducted on April 22, 2010 to determine the City's methodology for determining how to rehabilitate and/or replace existing sanitary and combined sewers as well as manholes. Mr. Morgan has worked with the city for 15 years and has been closely involved with the selection and specification of technologies for the replacement and rehabilitation of sewer pipes and manholes.

3.3.1 Introduction. Indianapolis is located near the center of the state of Indiana in Marion County. The city's population is around 800,000, making it the 14th largest city in the U.S. and third largest in the Midwest. Indianapolis has a system of more than 3,000 miles of sanitary sewer and 672 miles of combined sewer, which includes approximately 65,000 manholes.

3.3.2 Renewal Program. Indianapolis's renewal program is, like most, driven by the city's budget and available funding for rehabilitation each year. The city has been under a CD with EPA since 2005 and all milestones are set to be finished by 2025. The rehabilitation projects address primarily I/I issues as well as structural failures. Some of the site-specific renewal challenges commonly encountered by Indianapolis include traffic control associated with working in such a large city, impacts to commercial businesses and the volume of flow that needs to be bypassed to complete projects. Each of these factors plays a large role in the technology selection process.

Indianapolis does not have an automated process for technology selection currently, but it could see the need for such a tool that it could give to new engineers as a place for them to begin learning about the technology selection process. The reason why Indianapolis does not have an automated process currently is primarily due to the cost-effectiveness and success of two rehabilitation technologies: (1) CIPP and (2) shotcrete.

For pipes with diameters smaller than 54 in. in need of rehabilitation, typically CIPP is the preferred method of choice. There are other technologies, such as fold-and-form, sliplining, and traditional open cut excavation which are approved for use by the City, that are usually bid against CIPP for small diameter rehabilitation projects. However, CIPP is used 95% of the time for typical conditions up to 48 and 54 in. when considering cost and technical viability and it has been used on pipes as large as 72 in. Open cut is used very rarely due to the cost-effectiveness of CIPP and although fold-and-form is approved for use in Indianapolis, the city does not usually receive bids specifying it. Pipe bursting is also approved for use, but is rarely used (only 3 or 4 times total) due to the additional cost of excavation for each service reconnection. Pipe bursting would be considered for segments in need of upsizing, but Indianapolis does not have much need for increased capacity.

Above 54 in., shotcrete is the predominant method of choice for combined and storm sewers due to its low cost and long service life. The American Concrete Institute (ACI) recommends its use for diameters of 48 in. and up, but Indianapolis has found it difficult to maneuver in 48 in. pipe with the shotcrete gun so it typically recommends 54 in. and above. When corrosion is an issue, which is not typical, shotcrete is eliminated from further consideration and the city would specify sliplining or CIPP. For large diameter sewers, sliplining has been used on about 20 segments in the past 15 years. Sliplining is typically specified when bypass pumping is difficult or costly, making it more cost-effective since the pipe can contain full or partial flow during installation with sliplining. Sliplining might also be specified for combined sewers when users are forced to treat their waste before discharging it into the sewer. CIPP is sometimes less cost-effective for large diameters due to the fact that CIPP requires surface bypassing, whereas shotcrete can be internally bypassed.

Other commonly used technologies include spot repairs by open cut or man entry and CIPP sectional liners, which are used on pipes that have no more than one trouble location needing rehabilitation. Typically, if two or more spot repairs are needed, a full length repair is done. Laterals are not rehabilitated since the property owner is responsible for their lateral all the way to the main. After a main has been rehabilitated, the laterals are either reconnected (on open cut, sliplining, and shotcrete projects) or reinstated robotically on CIPP projects. A summary of the technologies typically being used by the City are shown in Table 3-10.

Table 3-10. Summary of Technologies Used

Small Diameter (<54")	Large Diameter (>54")
CIPP (95 %)	Shotcrete
Open Cut	Sliplining
Spot Repairs (< 2 repairs)	CIPP
	Open Cut
	Spot Repairs (< 2 repairs)

3.3.3 Technology Selection Methodology. Although Indianapolis's technology use is very well understood by the City, it is still important to document their methodology for rehabilitation. Indianapolis' typical approach to the method selection process for pipe replacement and rehabilitation includes consideration in the following four areas: (1) condition assessment; (2) environmental conditions; (3) capacity issues; and (4) cost-effectiveness.

The City obtains condition assessment data in the form of CCTV surveys and then assessments of the data are made by qualified engineers, either in-house or consultants, to determine the associated PACP codes. In addition to the pipe condition assessment, the engineers will also assess other variables, such as environmental and capacity issues, which must be taken into account during the selection process to determine the viability of each particular technology. These variables typically include, but are not limited to: (A) traffic conditions at the project site; (B) flow capacity; (C) pipe length; (D) pipe depth; (E) pipe diameter; (F) bypass considerations; and (F) the inclusion of upstream contributors.

The cost-effectiveness of a technology includes many variables in addition to the material and labor required to use a technology. Other cost parameters include surface restoration costs due to trenching and access pits and reinstatement of the laterals and traffic control costs. Access pits are required on sliplining projects at off-set locations, which increase cost and disruption. Indianapolis's method selection process is summarized in Table 3-11.

Table 3-11. Summary of Indianapolis's Method Selection Parameters

Condition Assessment Data
CCTV Surveys, PACP Codes, Site/Traffic Conditions and Pipe Length, Depth, and Diameter
Environmental Conditions
Upstream Contributors
Capacity Issues
Flow Capacity and Bypass Consideration
Cost-Effectiveness
Material and Labor, Surface Restoration, Lateral Reinstatement, Access Pits, and Traffic Control

Once a technology has been selected, the City will prepare the project plans and specifications on which the contractors will then bid. Indianapolis uses standard specifications for each of the technologies approved by the City and makes minor modifications based on each specific project. The alterations to the standard specifications are always discussed and pointed out in the pre-bid meeting so that everyone is clear on what is unique about the project. Also, the minutes of the pre-bid meeting are always sent out as contract addenda to each contractor so that all bidders have the information whether they attended the meeting or not.

After the discussion during the morning, a field visit of the city was taken in the afternoon. An ongoing project called the Merrill Street Combined Sewer Rehabilitation, which required the rehabilitation of approximately 2,100 lf of 60 in. and 700 lf of 66 in. concrete combined sewer that was built in the 1950s was visited. Figure 3-4 shows the amount of bypassing pumping and piping required, which closed two of the five lanes near Alabama St. and Henry St., which nearly eliminated CIPP from being selected. Generally, the cost of bypass pumping is what Indianapolis tries to work around, due to the large volume of flow in the medium to large size segments that are attached to the interceptor system. However, for this project other factors played a larger role than bypass requirements which are described below.

Figure 3-4. Bypass Pumping and Piping Required for CIPP Operations on Merrill Street

For this project, all of the large diameter remediation options were considered and three were evaluated before making the final rehabilitation method selection. The amount of bypass could have been reduced had sliplining been used, but due to the slight alignment changes at the majority of the manholes, which required access pits at each location, it was more cost-effective to use CIPP, which would eliminate the need for multiple access pits. The multiple access pits would have had a more significant impact on the traffic than the closure of the two lanes for the bypass system. There was also a high volume of adjacent utilities along the alignment which would have made digging access pits very difficult and time consuming. Shotcrete was also considered, but it was eliminated from further consideration due to concerns about capacity and corrosion. Table 3-12 summarizes the method selection recommendation made by a local consultant which was provided to the city.

Table 3-12. Summary of Rehabilitation Recommendations

Option	Considerations	Comment
Open Cut	Not considered due to the: (1) depth of the sewer; and (2) proximity to utilities and major thoroughfares.	Only trenchless options were evaluated
Shotcrete	Eliminated from consideration due to: (1) a slight capacity increase (~4%); and (2) concerns about corrosion of the material.	Eliminated despite being cheaper than CIPP and sliplining
Sliplining	Eliminated from consideration due to the: (1) need for access pits at each alignment change; and (2) larger impact on traffic conditions.	Eliminated despite requiring less bypass than CIPP
CIPP	Recommended and selected due to: (1) limited excavations since the liner can negotiate bends; and (2) the significant capacity increase (~45%).	Engineer's estimate at 90% design was around $3.9 million

Also during the site visit, several manholes were popped open to view the condition of cementitious coatings that had been applied in conjunction with mechanical seals. Other spray-on coatings and liners have been demonstrated, but cementitious coatings are the typical repair method for manhole rehabilitation.

3.3.4 Conclusions and User Needs. Mr. Morgan indicated that Indianapolis would be interested in a tool or guide that could provide more alternatives for rehabilitation of wastewater pipes and their associated regional costs, although they are not interested in purchasing one. The tool would need to be user friendly by giving the user the option to alter or customize the input based upon current market conditions and their respective changes. The tool would also need to contain or be able to import cost parameters for the various bid items associated with each technology. Indianapolis would use this tool to train new engineers in the process of condition assessment, technology selection, and cost consideration. The tool would also need to include technology case histories, including reference material that the user could use to obtain more information regarding the use of a technology. The case histories would need to contain the contact information of other municipal users who have used the technology successfully or unsuccessfully. This would be key in the sharing of knowledge and providing lessons learned from past rehabilitation projects.

Contact: John Morgan, (317) 327-8053, john.morgan2@indy.gov

3.4 Case Study #4: City of Las Vegas, Las Vegas Valley Water District

A meeting with Mr. Charles Scott, the Engineering Project Manager for the Las Vegas Valley Water District (LVVWD) Asset Management (AM) group took place on May 18, 2010 to determine the city's typical methodology for deciding how to rehabilitate and/or replace existing water mains. Mr. Scott has been with LVVWD for seven years and has led the AM group since 2007. In 2008, LVVWD implemented the CARE-W program, a suite of tools for determining short-term and long-term pipe rehabilitation needs.

3.4.1 Introduction. Las Vegas is the largest city in the state of Nevada and the county seat of Clark County, which is located in the southern tip of the state. The city has about 570,000 residents, making it the 28th largest city in the U.S., with a customer base of around 1.1 million including unincorporated parts of Clark County. LVVWD is a not-for-profit agency that began providing water to the Las Vegas Valley in 1954. The District now provides water to more than one million people in southern Nevada. LVVWD is one of seven member agencies that make up the Southern Nevada Water

Authority (SNWA), a regional agency formed in 1991 to address southern Nevada's unique water needs on a regional basis. The District also acts as the managing agency for the Water Authority. LVVWD operates and maintains water systems in the outlying communities of Laughlin, Blue Diamond, Coyote Springs, Jean, Kyle Canyon, and Searchlight, Nevada. The Clark County Commissioners serve as the Water District's board of directors. The board appoints the general manager, who carries out day-to-day activities.

LVVWD infrastructure includes over 350,000 active services, 4,500 miles of piping 4 in. diameter and larger, 51 water reservoirs with a total capacity of 935 million gallons, and 60 booster pump stations having combined pumping capacity of nearly 1.25 million gallons per minute. Water distribution and transmission piping is 51% PVC, 0.03% cast iron, 9.5% steel, 3% ductile iron, and 36% asbestos cement. The average age for all piping is 19 years: with asbestos cement pipe averaging 31 years; cast iron pipe averaging 45 years; ductile iron pipe averaging 8 years; PVC averaging 9 years; and steel averaging 20 years. The 2009 break-rate per mile was around 0.02 breaks/mile.

The District's "first wave" of pipe replacements focused on high failure rate cast iron piping. From the 1970s to 2006, LVVWD replaced almost all (roughly 90 miles) of its cast iron pipe. The AM group is now developing the tools and methodology needed for the "next wave" of pipe replacement/rehabilitation. In addition to pipe replacement and rehabilitation planning, AM manages a corrosion control program to extend the life of steel piping and steel infrastructure.

3.4.2 Renewal Program. LVVWD currently enjoys a relatively young distribution system with low break rates and low water losses, but AM has estimated that over $100 million (in 2010 dollars) of piping may be in need of replacement in the next 20 years. To address this, the AM group has developed and is currently implementing a distribution system asset management plan for long-term and short-term replacement and rehabilitation. The primary objective of the plan is to maintain distribution system integrity at a level that meets customer cost and service expectations by replacing the right pipe at the right time, in the most cost-effective, and non-disruptive means possible.

The key elements of the plan are to: (1) establish and monitor distribution PIs; (2) perform pipe condition assessments to determine short-term replacement needs; and (3) make renewal decisions that are prioritized based on condition assessment results, hydraulic criticality, and location specific consequences. Distribution system PIs are an indication of the overall state of the system and they include: average system age, break rates per mile, infrastructure leak index (ILI), and number of service interruptions.

LVVWD typically uses in-house designers for making recommendations and writing specifications for how to replace or rehabilitate its existing water mains. Currently, LVVWD does not use any automated decision support tools for technology selection, but would find one useful if it could be integrated with its GIS and CARE-W tool. The need for a rehabilitation selection tool has been limited due to the fact that the majority of repairs and replacement have been done by open cut construction. However, being that the city's system is only now starting to reach the end of its design life; more options will be needed to address the future rehabilitation needs of the water system.

Cast iron water main rehabilitation and replacement is accomplished by open cut construction. Service laterals up to 2 in. have been replaced via pipe bursting, but no water main pipe bursting projects have taken place as of yet. In areas where access is limited and upsizing is needed, pipe bursting or splitting would be considered to rehabilitate short segments of CI or steel pipes. LVVWD is currently considering structural CIPP options for water main rehabilitation in sensitive areas where pipe bursting is not an option due to either (1) the need for multiple access pits or (2) the inability to pipe burst AC pipe which creates a regulated waste site when the pipe is broken into the ground. A summary of the technologies typically being considered by LVVWD for water main rehabilitation and replacement is shown in Table 3-13. Open cut for full length replacement and spot repair are the only technologies being used for renewal projects.

Table 3-13. Summary of Water Technologies Used

Water Main Technologies
Open Cut (Full Length or Spot Repair)
CIPP (Considering)
Pipe Bursting (Considering)
Sliplining (Considering)

As noted earlier, one of the unique challenges facing LVVWD is the fact that 36% of the water system is made up of asbestos cement pipe. For asbestos cement pipes, pipe bursting was initially considered to be the most viable option since the utility would most likely be able to avoid hazardous pipe material removal by using open cut. However, it was determined that pipe bursting asbestos cement pipe would create a regulated waste site once the pipe was broken into the ground. This has made pipe bursting unacceptable and LVVWD is now considering structural CIPP for water main rehabilitation.

3.4.3 Technology Selection Methodology. LVVWD's number one deciding factor for determining when and how to replace or rehabilitate water main assets is balancing the risk of failure against the cost of renewal. LVVWD utilizes a suite of software tools, which were developed in Europe, called CARE-W to identify the most at-risk pipes for condition assessment surveys. The condition assessment prioritization is based on the Annual Rehabilitation Planning (ARP) tool, which is comprised of three factors that can all be weighted based on the user specified level of importance: (1) statistical failure mode; (2) hydraulic criticality index; and (3) a multi-criteria decision-making tool.

The statistical failure model is used to determine each pipe's failure index or the likelihood of failure. The hydraulic capacity index is calculated by removing a pipe from the system model and then analyzing the system to determine the consequence of failure. Finally, a multi-criteria decision-making tool, which includes parameters such as: impact on roads and business; customer type; and size, is used to determine another form of the consequence of failure. By evaluating each of these parameters, LVVWD is able to determine which pipes in the system are the most critical, and then the inspection can be planned appropriately. Figure 3-5 outlines how the ARP tool fits into the CARE-W program.

Whenever possible, condition assessments are carried out using non-invasive acoustical wave technology from Echologics®. Over the past couple of years, AM has helped develop and validate the use of this technology for condition assessments. As of 2009, about 20 miles of pipe had been assessed, of which about 7% was found to be more than 20% degraded. AM also uses pipe-to-soil potential readings (where available), and direct assessment as the opportunity arises. Assessment data are posted as a layer onto the District's GIS for spatial analysis. Once the most at-risk pipes are determined from the condition assessment, LVVWD is able to locate which sections actually require renewal.

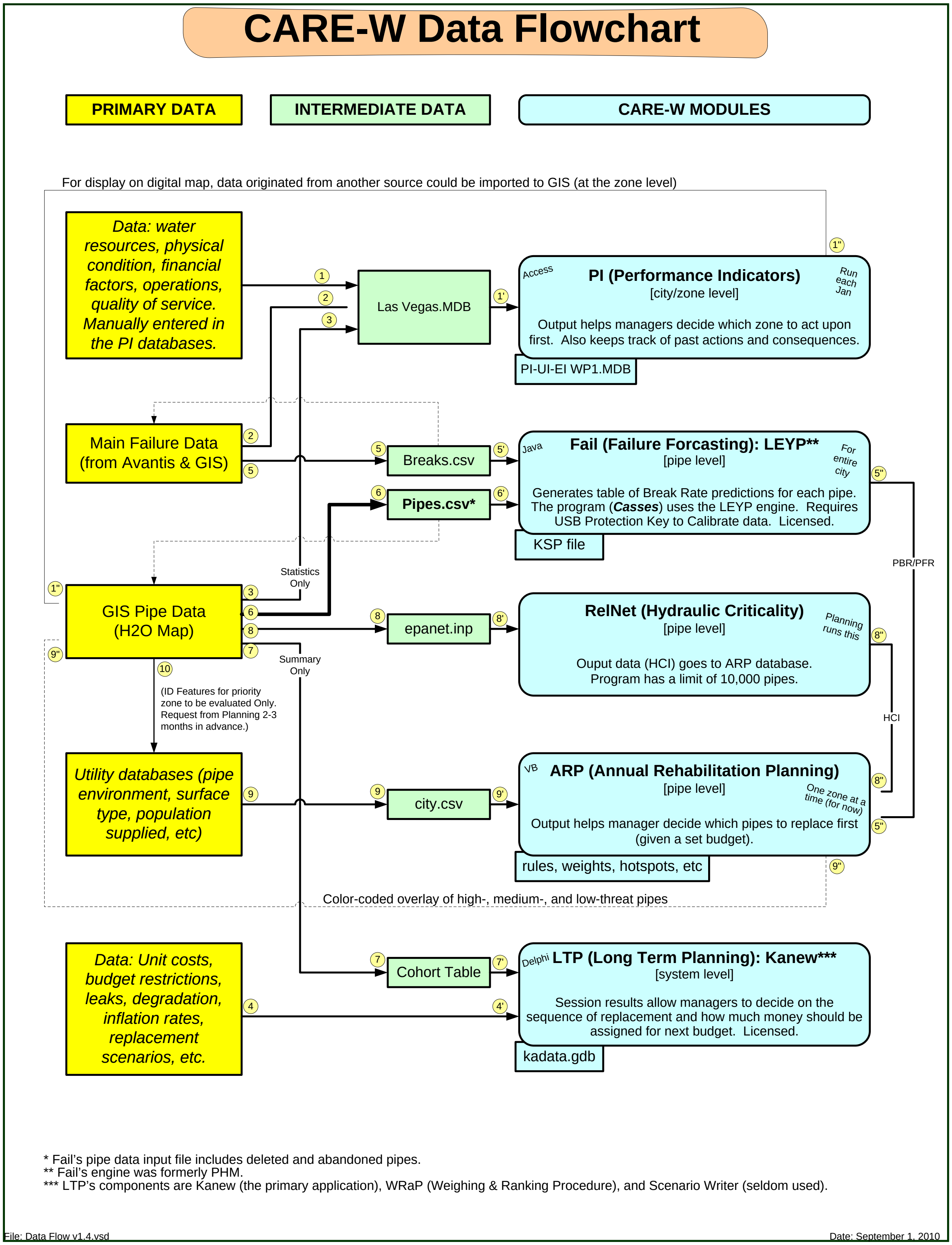


Figure 3-5. CARE-W Data Flowchart

Once a section is identified for renewal, four types of information must be determined: (1) any surface encumbrances; (2) water main characteristics; (3) water main connections; and (4) technology cost analysis. The location of surface encumbrances is used to determine first if open cut is an option. Significant surface encumbrances play into the technology selection process because they increase both the direct construction costs and the social costs. One location that creates accessibility issues is under a freeway underpass, which virtually prohibits open cut no matter how expensive lining or bursting may be.

Pipe characteristics that come into play during the method selection process include length, diameter, depth, and pipe material. Also, whether or not a section has connections, valves and/or hydrants is important in the selection process. The more valves and hydrants a segment has, the less advantage there is to using lining or bursting since each location would require an excavation.

If the lack of significant surface encumbrances deems open cut to be applicable, LVVWD performs a cost analysis of each of the various rehabilitation technologies as well as open cut. If the cost of lining or bursting is less than the 60 to 70% of open cut (rule of thumb break point), lining or bursting is considered more advantageous. If not, open cut would be considered a viable option based on the longer anticipated service life of a new pipe compared to a lined pipe. Some specific parameters that play into the cost analysis are costs of crew relocating, rerouting of utilities, traffic control, project duration, mobilization, demobilization, utility crossing, dust control, interruption to service, and surface restorations. Table 3-14 summarizes all of the method selection parameters.

Table 3-14. Summary of LVVWD's Method Selection Parameters

Surface Encumbrances
Open Cut an Option or Not
Pipe Characteristics
Length, Diameter, Depth, and Pipe Material
Main Connections
Service Connections, Valves, and Hydrants
Cost Analysis
Crew Relocating, Mobilization, Rerouting Utilities, Duration, Surface Restoration, and Traffic Control

As mentioned above, LVVWD's goal is economy of scale, which is achieved by balancing the risk of failure and the cost of remediation, thereby providing the best product to the customer. The decision comes down to the cost-effectiveness of alternative technologies versus traditional open cut where applicable. The final decision typically involves the use of open cut unless surface encumbrances prevent its use or lining or bursting technologies are less than 60 to 70% of the cost of open cut construction.

3.4.4 Conclusions and User Needs. Mr. Scott made it known that LVVWD believes that a tool capable of estimating the various cost items relating to particular technologies could be useful at least as a reminder to the design engineer to consider all of the different cost elements. A greater need would be for a tool that could provide more alternative rehabilitation options for water mains along with their associated regional costs, specifically since LVVWD only recently started developing its renewal program. Another feature that would make the tool even more valuable would be the inclusion of method case histories for new technologies and reference information for further research as to past use by other municipalities and utilities.

Contact: Charles Scott, (702) 258-3281, charles.scott@lvvwd.com

3.5 Case Study #5: City of Los Angeles, Wastewater Program

A meeting with Mr. Keith Hanks, a Senior Sanitary Engineer and two members (Mr. Richard Pedrozo and Mr. Mario Dimzon) of the wastewater planning and design groups was conducted on May 19, 2010 to determine Los Angeles's selection methodology for determining how to rehabilitate and/or replace existing underground wastewater utilities. Mr. Hanks has worked for the City of Los Angeles for 25 years as an engineer designing and specifying technologies for use in the replacement and rehabilitation of wastewater utilities. Mr. Pedrozo is a design engineer for the Wastewater Conveyance Engineering (WCE) Division and has worked for the city for 19 years as a Civil Engineer. Mr. Dimzon is an Environmental Engineer for Wastewater Engineering Services (WES) in the Bureau of Sanitation and has worked for the city for 8 years.

3.5.1 Introduction. Los Angeles is located in Southern California and is the second largest city in the U.S. behind New York City. Los Angeles's population is around 3.8 million, making it the largest city in the western U.S. Los Angeles has a system of more than 6,500 miles of sanitary sewer. The city budgets a three-year average of $88 million in wastewater improvement projects each year.

3.5.2 Renewal Program. The City of Los Angeles is currently in the midst of its 60 Miles Program (60 MP), in which it is attempting to rehabilitate or replace an average of 60 miles of wastewater pipe each year. The program began in 2004 as part of an agreement with the EPA, Regional Water Quality Control Board (RWQCB), Santa Monica Baykeeper, and other stakeholders. The city was first divided into 240 sewer basins with the 100 most critical being scheduled for remediation during a seven year period (2008-2014). The top 100 basins were prioritized based on information such as sewer spills, pipe age and material, root intrusions, and capacity. Fifteen basins are planned each year and the construction on these basins began in 2008, with an average of 60 miles being remediated each year, and it is set to be complete in 2014. Currently, 77 of the 100 sewer basins have been planned and designed and 40 contracts have been awarded. 60 MP program is intended to address sewer mains that have structural problems, capacity issues, root intrusions, grease from restaurant emissions, spills, and corrosion. Some of the site-specific rehabilitation challenges for Los Angeles include (1) traffic mitigation and (2) narrow hillside streets.

Los Angeles utilizes an in-house planning group and design department and associated guidelines for recommending and specifying technologies for rehabilitating and replacing existing wastewater mains as part of their 60 MP. The planning group uses an automated tool called SPOT (Sewer Planning Optimization Tool), which was developed by an external engineering consultant firm, to recommend methods to the engineering design group. This tool is linked to their GIS system, which contains an extensive amount of data which the designers can use to help make their decision.

Los Angeles utilizes various technologies for the rehabilitation and replacement of small diameter sewer mains. These technologies include CIPP and fold-and-form in addition to full length and spot repair open cut replacement. For both structural and non-structural situations, Los Angeles specifies the required thickness of liner or pipe in the specifications. No successful sliplining bids have been received for the 8 to 15 in. mains, but sliplining is an option on large diameter sewers where capacity is not a limiting factor and bypass pumping is difficult. Spiral wound lining is typically considered as an option, but there is concern about the grouting around the laterals which tends to make it non competitive in the bids. Other large diameter options are grout-in-place corrosion barriers and open cut replacements using either PVC or HDPE pipe. Under 60 MP, if a pipe requires installation of a new pipe and the access is restricted, which might lend the project to pipe bursting, the pipe is moved into the difficult access reaches program (DARS). Currently, pipe bursting is not typically being used under the 60 MP. WCE is also considering using the tight-in-pipe (TIP) method, modified sliplining/pipe bursting, if and when a U.S. standard pipe size is developed by the manufacturer. Currently, all of the pipes developed for use with this technology were developed using Canadian standard pipe sizes. A summary of the technologies typically being used by WCE is shown in Table 3-15.

Table 3-15. Summary of Wastewater Technologies Used

Small Diameter Technologies	Large Diameter Technologies
Open Cut (Full Length and Spot Repair)	Open Cut (Full Length and Spot Repair)
CIPP	CIPP
Fold-and-Form	Sliplining
Pipe Bursting	Grout-in-Place Pipe
	Spiral Wound Lining

Los Angeles does not rehabilitate sewer laterals because they are owned all the way to the main by the property owner. The condition of the sewer lateral is the responsibility of the property owner. Manhole rehabilitation can be done by various methods approved for use by the city including spray-on polyurethane and epoxy coatings and perhaps CIPP manhole liners in the future, but generally manholes are replaced with new manholes protected by grout-in-place PVC corrosion barrier liners.

3.5.3 Technology Selection Methodology. The City of Los Angeles, like most cities, bases its technology selection decision on the most cost-effective solution that is capable of completing the job adequately. To help support the decision, WCE's planning group utilizes a tool called SPOT to help determine the best way to remediate existing sewer mains. SPOT is linked to their extensive GIS system, which includes information such as: details about the sub-structure, pipe dimension data, location maps, as-built maps, and aerial photos.

The input for SPOT, in addition to the GIS data mentioned above, are the defect codes obtained from condition assessment surveys (via CCTV). WCE performs a survey of each basin within the 60 MP before the planning group can make its recommendations. The inputs for SPOT include: (1) condition assessment codes; (2) number of defects; (3) section length; (4) diameter; (5) pipe material; and (6) age. Sewers that can't be videoed or surveyed are ranked based on the sewers around them, which are called correlation reaches, and then the contractor makes a decision once they get access to the particular sewer as to the best mode of remediation. Table 3-16 outlines the parameters needed in the WCE method selection process.

With these inputs, the planners are able to determine whether a pipe should be replaced, lined, addressed with a point repair or requires no action. In general, for segments with major defects more than 100 ft apart on average or bend and sag defects, point repairs are recommended. Replacements are required for small diameter pipes with root defects. Lining repairs are recommended for small diameters pipes which don't have corrosion and have been inspected to at least 80% of their length (Dimzon et al., 2008).

Table 3-16. Summary of Los Angeles's Method Selection Parameters

Condition Assessment
Condition Assessment Surveys, Associated Defect Codes, and Number of Defects
Pipe Dimensions
Pipe Length, Diameter, Depth, and Accessibility
Pipe Characteristics
Material, Age, Flow Capacity, and Bypass Considerations

Once the planning and ranking of a sewer basin is complete and the recommendations are made and packaged for each of the sewers in the basin, the report is turned over to the design team. The design team then determines if the recommendations are adequate for addressing the problems in the basin and develop their schedule of repairs accordingly. The schedule of repairs, which includes the type and thickness of liners, is prepared using the Sewer Management Automated Repair Tracking System (SMARTS) tool which was developed specifically for 60 MP. SMARTS has a built-in cost estimator which incorporates recent bid prices, economic adjustment factors and is integrated into the GIS system. Some of the key cost parameters include depth, which is key to excavation, specifically for pipes deeper than 20 ft.

Once design is complete, WCE provides a schedule of repairs for each pipe being rehabilitated in a particular basin (which includes the condition assessment, associated recommendation for rehabilitation or replacement) to the contractor as well as pipe specific details such as material (which must come from the list of approved materials), diameter, depth, connections, and adjacent utilities. The contractor will then use the schedule of repairs to develop its bid package. Figure 3-6 is an example of a schedule of repairs which includes three pieces that must be replaced by spot repair prior to full length rehabilitation. A typical set of plans will include a schedule of repairs for each pipe that needs addressing.

Members of WCE mentioned that contractor training may be a possible future requirement for a successful bid. This might eliminate inexperienced or untrained contractors from winning bids and produce better results on construction projects.

SCHEDULE OF REPAIRS

PROJECT TITLE: SSRP H35 Griffith & Franklin
WORK ORDER NO. : SZC11890

CROMWELL AV

U/S MH	D/S MH	STATIONING U/S (ft)	STATIONING D/S (ft)	LID ELEV U/S (ft)	LID ELEV D/S (ft)	INV ELEV U/S (ft)	INV ELEV D/S (ft)	MAX DEPTH (ft)	SEWER PIPE LENGTH (ft)	SEWER PIPE SIZE (inch)	MATERIAL	No. HC /WYE	CL_OFFSET	BEDDIN CASE
468-05-154	468-05-153	3 + 88	0 + 00	602.0	594.6	590.4	587.3	12	388	8	VCP	11	varies	1

REPAIRS

U/S STA (ft)	D/S STA (ft)	LENGTH (ft)	MAX R&R DEPTH (ft)	METHOD	PIPE MATERIAL	SIZE	HC RECONNECT	BEDDING CASE	HC STATIONS	COMMENTS
3+86	3+80	6	7	R&R	VCP	8	1	1	3+ 84R	
3+45	3+39	6	8	R&R	VCP	8	1	1	3+ 41L	
1+88	1+80	8	10	R&R	VCP	8	1	1	1+ 85R	
3+86	0+02	384		Rehabilitation by Non-Structural Lining			All			

SUBSTRUCTURES / UTILITIES

DESCRIPTION	CROSSING	PARALLEL OFFSET	COMMENTS
4" LAG & E		20' SN	
8" DWPWS		27' NS	
ABND 4" LAG & E	0+12		
2" SCG	0+33		

WASTEWATER CONVEYANCE ENGINEERING DIVISION
BUREAU OF ENGINEERING
CITY OF LOS ANGELES

NO.	REVISION DESCRIPTION	DIV./DIST.ENGR.	DATE

KEYMAP REF.: C- 1

INDEX NUMBER	SHEET
	44

Figure 3-6. Example Schedule of Repairs

3.5.4 Conclusions and User Needs. Mr. Hanks indicated that Los Angeles is comfortable with its method selection process and level of automation. The SPOT tool is useful at recommending various alternatives and SMARTS is capable of providing reliable cost estimates based on various factors. The need for method case history information is irrelevant currently because any material and technology available for use in Los Angeles must go through the city's approval process. Mr. Hanks acknowledged that the cost for a vendor to have their product approved, while not guaranteeing that the product will ever be used, makes it difficult for vendors to justify the expense. An approval process that could be certified by multiple utilities could make the process more appealing for vendors to participate in.

Contact: Keith Hanks, (213) 485-1694, keith.hanks@lacity.org

3.6 Case Study #6: City of Atlanta, Rehabilitation Design Program

A meeting with Mr. Ray Hutchinson, a Vice President for MWH and the City of Atlanta's Program Management Team (PMT) consultant; design engineer, Mr. Cornell Gayle; and the City of Atlanta's Rehabilitation Design Manager, Ms. Rebecca Shelton was held on May 26, 2010 to discuss the City of Atlanta's methodology and associated parameters/criteria for determining how to rehabilitate and/or replace existing sanitary sewer gravity pipes and manholes through the use of its Rehabilitation Selection Tool (RST). Mr. Hutchinson has more than 35 years of experience as an engineer in the area of sewer rehabilitation design and construction and he has worked with the City of Atlanta on its Rehabilitation Design Program since 1999.

3.6.1 Introduction. Atlanta is located in northwestern Georgia. Atlanta has a population of about 541,000 people, making it the largest city in the state of Georgia and the 33rd largest city in the U.S. The city maintains more than 1500 miles of sanitary sewer assets and approximately 37,500 manholes (Hunter and Sukenik, 2007). At present around 340 miles of the sanitary sewers or 22% have been lined or replaced under the current Rehabilitation Design Program (RDP). Currently, 88% of the City's sanitary sewer system has been inspected as have a similar percentage of the manholes. The City's goal under the current CD is to survey, inspect, review, and upload the rectified data into GIS for each and every sewer pipe and manhole by the end of the CD period and to design appropriate remedial actions accordingly or defer the asset to Capacity Management Operations and Maintenance (CMOM) in a structured way relative to severity and criticality.

3.6.2 Renewal Program. The City of Atlanta is currently in the middle of an SSO CD with the EPA and it has already completed a CSO CD. The SSO CD took effect in 2004 and was originally scheduled to be completed by 2014, but due to funding limitations, the city has requested a 15 year extension on the remaining work, which would last until 2029. Since 2004, the number of SSO spills has been reduced by 75% and the volume of SSO spills has been reduced by 97%.

The PMT's Rehabilitation Design Team is made up of both in-house designers and outside consultants who all utilize design guidelines, a fully integrated, Web-based GIS system and a Web-based decision tool to design the appropriate rehabilitation and/or replacement solutions for each sewer pipe and manhole in the city's system. The RST was developed by an outside consultant in conjunction with city personnel to assist designers with their decision of determining how to replace or rehabilitate existing sewer pipes in the most cost-effective manner (Hutchinson et al., 2007).

The primary options for small diameter sewer rehabilitation and replacement include CIPP, pipe bursting (with either HDPE or ductile iron), external point repairs using open cut, internal point repairs using either mechanical or CIPP sleeves, horizontal directional drilling (HDD), and open cut replacement. In addition to small diameter solutions, technologies being used on larger diameter sewers include sliplining (when capacity reduction is not an issue), CIPP, spiral wound lining, chemical grouting, shotcrete, pipe bursting, segmental lining, and open cut replacement. Undersized pipe needing to be replaced and upsized is typically done with either online pipe bursting, open cut techniques or off-line HDD. To date, over 276 miles of sewer has been lined, 43 miles has been replaced using pipe bursting, and over 20 miles has been replaced using open cut construction. Many sewers of all sizes have also been replaced off-line using jack and bore and microtunneling techniques. A summary of the technologies typically being used by Atlanta is shown in Table 3-17.

Table 3-17. Summary of Wastewater Technologies Used

Wastewater Technologies
CIPP (Full length and Point Repair)
Pipe Bursting
Open Cut (Full length and Spot Repair)
Sliplining (Large Diameter)
Spiral Wound Lining (Large Diameter)

Atlanta also performs rehabilitation of laterals typically by local point repair, lining, open cut replacement or, very occasionally, pipe bursting from within the property. Remedial action applies to the lower lateral, i.e., from the mainline sewer to the edge of the right-of-way (ROW), normally finishing at a newly installed double sweep clean-out. The property owner is responsible for maintaining the upper lateral. The pipe bursting option is adopted for use with lower laterals only when there are utilities to pass under and/or if the lateral is long and relatively shallow under landscaping. Otherwise it is more cost-effective and expedient to replace the lower lateral using open cut replacement. The lateral technology selection procedure takes into account accessibility, number of laterals (normally open cut is preferred to pipe bursting if there are more than seven laterals in any given segmental length), whether or not the remedial action is being done in conjunction with a clean out installation (normally at the edge of the ROW) and the presence of intervening features on the lateral such as trees, fences or hydrants.

Atlanta also performs manhole rehabilitation which includes the use of full replacement, epoxy or cementitious lining, fiberglass lining, chemical grouting, frame and/or cover replacement, or chimney sealing. The technology selection would depend on the condition of the manhole and whether it required a corrosive barrier, structural lining, I/I barrier or full replacement.

3.6.3 Technology Selection Methodology. The City of Atlanta utilizes a Web-based asset management tool which is integrated into its GIS system and incorporates Sanitary Sewer Evaluation Survey (SSES) data to categorize every single sewer pipe and manhole in their system (Brown and Toomer, 2007). The Web-based system contains RST, which is used to design the rehabilitation or replacement of each sewer pipe and manhole if any action is determined to be needed or to assign the pipe or manhole to the CMOM category for future implementation. This tool helps to determine the most cost-effective solution for rehabilitation or replacement.

The RST designs are done for each sewershed, which is made up of a discrete drainage area containing between 10,000 and 50,000 ft of pipe. Each design includes methodically reviewing each sewershed segment by segment as necessary. The designer is able to zoom in on each segment and get a detailed view of the defects for each particular segment within the sewershed.

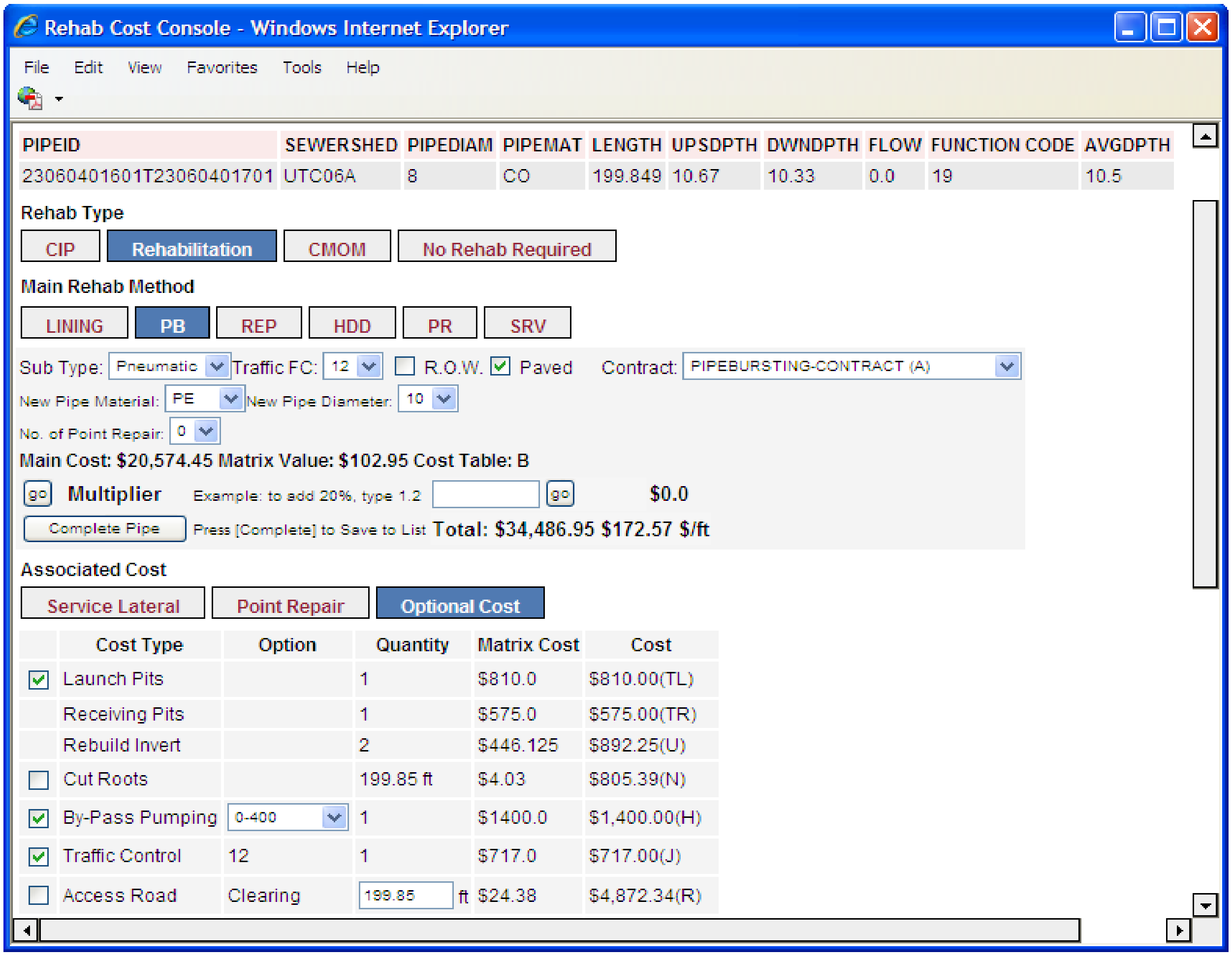
During the design process, references are made to the extensive amount of data included in the GIS systems such as: (1) pipe defects, CCTV videos, and hydraulic modeling results to determine if a pipe needs to be resized or the slope needs to be changed (Bechara et al., 2007); (2) GIS maps, global positioning system (GPS) location, easement reviews, and site photos; (3) segment parameters and characteristics (length, diameter, depth, material, age, previous rehabilitation, and deformation); (4) cost-effectiveness of various repair methods (multiple spot repairs versus a full length solution) and constructability reviews; and (5) appropriate technologies chosen for other pipes and/or manholes in the proximity of the sewershed under consideration. The main rehabilitation selection is based on the presence and frequency of a group of essential structural defects such as breaks, holes, fractures, deformations (if the deformation is greater 10%, linings are not used and either pipe bursting or open cut techniques would be considered), joint displacements, etc. Based on these data, the designer is able to make a sound decision as to the most cost-effective and least disruptive technology capable of restoring or replacing the existing pipe or manhole to an adequate condition. The designer must consider all elements of information within the system such as the technology selection data and parameters which are utilized within RST (Table 3-18).

Table 3-18. Summary of Atlanta's RST Technology Selection Data and Parameters

Condition Assessment
Type/Number of Defects, CCTV Videos, and Hydraulic Modeling Results
Site Accessibility
GIS Maps, GPS Location, Easement Review, and Site Photos
Segment Characteristics
Length, Diameter, Depth, Material, Age, Previous Repair, and Deformation
Cost-Effectiveness
Cost Items Relating to Various Technologies and Constructability Reviews
Other Utilities
Technologies Chosen for Other Assets in the Proximity of the Sewershed

Specific cost parameters considered by the RST include: pipe material, depth, and diameter; ROW vs. non-ROW; the sewer, lateral or manhole rehabilitation method; bypass pumping requirements; road classification; traffic control requirements; obtaining access; and total surface remediation options. Cost consideration for degree of difficulty (i.e., difficult access) and contingency matters (e.g., night working) are also provided for in cost estimation portion of RST. Figure 3-7 shows a screen shot from RST and outlines some of the cost parameters associated with a typical pipe bursting project. Cost factors include launch pits, receiving pits, bypass pumping, and traffic control.

After a sewershed has been designed, and easement and constructability reviews have taken place, Atlanta puts together either a defined contract or undefined contract. *Defined* contracts are configured to have both the location and construction method specified for the contractor to bid on and the contractor bids a unit price for the defined quantities derived from SSES information for a particular sewershed area. *Undefined* contracts have only the construction method specified and the contractor bids a unit price for the quantities estimated by the city for typical quantities of work required to be carried out outside of the specific sewershed areas. Approximately 75% of the work is done using defined contracts, while the other 25% is accomplished with undefined contracts.



Notes: Function Code: Fulton County Road Classification
Multiplier: Engineering Judgment Concerning Degree of Difficulty
Abbreviations s hown a fter uni t c ost i ndicate t he t able i n t he cost m atrix from which t he i nformation ha s be en automatically drawn.

Figure 3-7. Screenshot from Rehabilitation Selection Tool

3.6.4 Conclusions and User Needs. Mr. Hutchinson and Ms. Shelton indicated that although the RST program used by the City of Atlanta is capable of estimating the various local cost items for technologies they frequently use, such as pipe bursting and CIPP, they would like to see a tool for estimating the various cost items relating to the use of other technologies. Also, if the tool could provide more alternatives for rehabilitation of sewer pipes and their associated regional costs, Atlanta would find it very useful, particularly if the tool included method case histories for new technologies and reference information from other cities that have used the particular technologies successfully and unsuccessfully.

Contact: Ray Hutchinson, (404) 979-6999, ext. 7254, raymond.hutchinson@mwhglobal.com

3.7 Case Study #7: City of New York, Department of Design and Construction

A meeting with Mr. Dino Ng, Associate Commissioner for the Department of Design and Construction (DDC) and Mr. Gurdip Saini, Assistant Commissioner of in-house design was held on May 28, 2010 to discuss New York City's process for determining how to rehabilitate and/or replace existing water mains, wastewater pipes, and manholes. Mr. Ng has worked for the City of New York for over 27 years, where he has been involved in designing and writing specifications for rehabilitation of water and wastewater systems. In New York, the DDC performs much like a consultant would for a municipality or utility, which, in this case, is the New York City Department of Environmental Protection (DEP) who is the owner of the both the wastewater and water systems in New York City.

3.7.1 Introduction. New York City is the largest city in the U.S. with more than 8.3 million people residing within its five boroughs. The city is located on a large natural harbor in the northeastern U.S. and is comprised of five counties: Bronx, Kings, New York, Queens, and Richmond. New York's sewer system consists of roughly 6,000 miles of pipe and the water transmission and distribution system is roughly 6,000 miles. The city performs around $250 million of work on water and wastewater rehabilitation and replacement projects each year.

3.7.2 Renewal Program. New York City's renewal program is primarily driven by conditions such as: (1) flooding; (2) main breaks; (3) sink holes and other emergencies; (4) road rehabilitation; (5) programmatic replacement based on age and the pipe material's remaining useful life; and (6) capacity. The DEP typically initiates sewer projects due to flooding issues such as undersized or lack of storm system storage or replacement of septic systems, which is backed up by hydraulic modeling. Some of the site-specific renewal challenges commonly encountered in New York City are: (1) non-round large diameter sewers; (2) difficult traffic conditions; and (3) enormous amounts of adjacent utilities as shown in Figure 3-8. The figure shows the adjacent utilities for a project on Fulton Street in Lower Manhattan.

Figure 3-8. View of the Extensive Utilities under Fulton Street in New York City

The City of New York's DDC has a staff of around 150 engineers with approximately 2/3 performing in-house design and the other 1/3 managing outside consultants. DDC will develop designs and make recommendations for how to replace or rehabilitate existing water and wastewater pipes to the DEP who then accepts or rejects the recommendations. DDC does not use any decision support software for this application nor does it see the need for an automated decision tool within its organization due to the years of experience within the group. It might be a good tool to give to new engineers who are learning on the job as a source of information, but the final decision would always be in the hands of an experienced engineer. DDC would, however, welcome a source where it could gather information on the use of alternative technologies from other municipalities and utilities that have used them in the past, which may apply to their needs.

For sewer remediation projects, DEP is typically a conservative owner, so DDC designs and recommends solutions accordingly. When conditions allow, CIPP is the first choice for pipes less than 36 in. in diameter unless the line is undersized. In large diameter brick sewers or non-circular pipe greater than 36 in. in diameter, shotcrete is the primary rehabilitation method. If conditions do not permit CIPP or shotcrete, then open cut replacement is the next choice. Pipe bursting was used once successfully, but it is not typically recommended due to concerns of possible damage to other adjacent utilities, including gas and telecommunications cables. Fold-and-form is generally not used unless a tight fit can be achieved. A summary of the technologies typically being used by New York City are shown in Table 3-19.

Table 3-19. Summary of Wastewater Technologies Used

Wastewater Technologies
Open Cut
Shotcrete (Large Diameter)
CIPP
Sliplining
Grout-in-Place
Spot Repairs

For water main remediation, New York City does not do a lot of lining because of the number of connections, bends, and joint offsets within a given segment. Water mains typically get replaced using open cut construction when the age and breaks reach a certain level. Water mains that were installed before 1945 get replaced and up-sized from 6 to 8 in. using ductile iron pipe for project areas involving sewer work. DDC has also used CIPP on an existing water main section which only had one or two connections. Another non-typical technology was used on a 48 in. cast iron host redundant trunk main running at 150 pounds per square in. (psi), which was in good structural condition but had a lot of built-up tuberculation. The redundancy allowed DDC to shut the main down on the weekends and to install 10,000 ft of 46 in. HDPE slipliner. This is not a typical technology and was only possible since this was a very straight run. CIPP was not considered for this application due to the size and length of the main, which created concerns about the applicability of the very new CIPP for water main rehabilitation that has mostly been used in Europe. A summary of the technologies being used by the New York's DDC for water main rehabilitation and replacement is shown in Table 3-20.

Table 3-20. Summary of Water Technologies Used

Water Main Technologies
Open Cut (99%)
Sliplining
CIPP

The city does not typically address laterals since they are owned all the way to the main by the property owner and therefore are the property owner's responsibility to maintain. New York City typically rehabilitates its manholes using cement mortar parging or flashing. The process of parging involves applying a minimum ½ inch thick finishing coat of mortar with a float finish on the inside surface area of the manhole.

3.7.3 Technology Selection Methodology. Once the DEP initiates a project due to the issues mentioned earlier, DDC will begin its design process by conducting an inspection of the segments in need of remediation. There is no annual inspection plan or prioritization tool primarily due to the sheer size of the system; therefore, DDC does not conduct an inspection until DEP initiates a project. If an increase in capacity is needed, then no condition assessment will be done to help make the decision and the pipe will simply be replaced to meet the needs of the required additional capacity. For sewers greater than 36 in., a walk through is required by DEP maintenance personnel before design and construction can begin.

From the inspection, DDC will obtain all of the necessary information it needs to complete its design and associated recommendation for DEP. As noted above, if the pipe in question lacks hydraulic capacity, DDC will not perform a condition assessment and the pipe will typically just be replaced using open cut (not pipe bursting for reasons mentioned earlier). DDC's recommendation otherwise will be based primarily on: (1) CCTV reports, defect evaluation, and capacity; (2) pipe characteristics (i.e., length, diameter, and depth); (3) traffic control considerations; (4) accessibility issues (i.e., width of site access, head room, proximity of other utilities, and other structures or piles); and (5) cost factors. Once DDC makes its recommendation DEP will review it and then the project is put out for bid. DDC's typical selection parameters are summarized in Table 3-21.

Table 3-21. Summary of New York DDC's Method Selection Parameters

Condition Assessment
CCTV Report, Defect Evaluation, and Capacity
Pipe Characteristics
Length, Diameter and Depth
Traffic Control Consideration
Specific Attention is Given to Traffic Control
Accessibility Issues
Width of Site Access, Head Room, and Proximity of Other Utilities and Structures
Cost Factors
Costs Databases for Past Projects

DDC stores its costs in databases from past projects, but they mentioned they would prefer to have pipe and excavation in separate categories to provide a more accurate estimate of where the money is being spent. This could allow DDC more flexibility in trying new technologies if they were able to show how an alternative technology could save them in terms of excavation and restoration costs. Traffic control is another important selection and cost parameter when selecting a technology due to the amount of vehicles in the city.

3.7.4 Conclusions and User Needs. Providing DEP with a cost-effective and conservative solution is the number one priority of the DDC. DDC makes its technology selection decisions based on the needs of DEP, which is to provide adequate service to its residents. Mr. Ng expressed interest in a tool that would include: (1) methodical case histories for new technologies; (2) reference information for further research if needed; (3) contact information of other municipal utilities who have used the technology successfully or unsuccessfully; (4) estimation of the various cost items relating to a particular technology; (5) more alternatives for rehabilitation of water and wastewater pipes; (6) regional cost data and various bid items associated with each alternative; and (7) a source for the data and any backup documents so the municipality can make its own judgment for how to apply it to their specific needs. He specifically mentioned how industry interaction helps drive technology selection and how interaction with other cities can help to obtain a firsthand account of how other cities have solved similar problems. Since DEP is generally conservative with its method approval, they generally allow only methods with which they are comfortable. This creates the need for DDC to have reliable information about new technologies, so that they know as much as possible about a technology before recommending it to DEP.

Contact: Dino Ng, (718) 391-2043, ngy@ddc.nyc.gov

3.8 Case Study #8: Miami-Dade County, Water and Sewer Department

A meeting with Mr. Rod Lovett, Chief of the Wastewater Collection and Transmission Line Division for the Miami-Dade Water and Sewer Department (WASD), was held on June 10, 2010 to determine WASD's process for determining how to rehabilitate and/or replace existing wastewater mains, laterals, and manholes. Mr. Lovett has been with WASD for over 20 years and has served as the chief of the wastewater collections division since 1995.

3.8.1 Introduction. Miami-Dade County is located at the southeastern tip of Florida on the Atlantic coast. It has a population of nearly 2.5 million people making it the second largest county in the state and eighth largest in the country. Miami-Dade wastewater system is made up of more than 6,230 miles of gravity collection and lateral pipes. WASD performs about $15 million in operation and maintenance each year and another $15 million in capital improvements.

3.8.2 Renewal Program. Miami-Dade WASD is currently about 16 years into the Dade County ordinance which requires a 5 to 10 year inspection cycle of every gravity sewer longer than 2,000 ft. The Well Field Protection Ordinance requires that all gravity collection basins within the maximum day cone of influence of a public drinking water well be inspected on a 5 year cycle and all other basins be inspected on a 10 year cycle. WASD also requires a 2 year inspection cycle on transitions from force mains to gravity mains, but that is not required by the ordinance. WASD signed a CD with EPA in 1992 and it was augmented in 1994. The CD was completed in 2001, although a portion pertaining to pump stations is still ongoing. The original CD and the current ordinance are intended to eliminate I/I from the system. Some of the site-specific challenges encountered in Miami-Dade include high groundwater levels and very corrosive environments.

WASD uses an in-house design evaluation team to determine how to replace and/or rehabilitate existing wastewater pipes cost-effectively based on its inspection data and an associated cost analysis. For small diameter sewers with a minimum size of 8 in. and relatively no capacity issues, WASD typically uses either: (1) CIPP; (2) fold-and-form, although not used as much anymore; (3) open cut replacement; (4) internal grouting for joint leaks, which is done in-house; (5) sectional CIPP, which is done robotically, using 6 to 8 ft liner lengths; (6) pipe bursting with either HDPE, ductile iron or PVC, which is not used as much due to higher costs associated with multiple lateral reinstatements; (7) point repairs using open cut; and (8) degreasers to eliminate grease and grease build-up, which is also done in-house. Grease is the cause of most of the blockages in the system and they have not had any capacity overflows since 1998. WASD has blanket contracts for CIPP, open cut replacement, and sectional CIPP already in place which are renewed every three years. CIPP is generally cost-effective, but it does not correct off-set joints and requires bypass pumping. A summary of the technologies typically being used by WASD for small diameter remediation is shown in Table 3-22.

Large diameter sewers are in good shape generally and are evaluated on a site-specific basis. Technologies typically used for remediation include: (1) open cut; (2) sliplining with fiber glass reinforced pipe; (3) CIPP, which has been used on pipes as large as 96 in.; (4) epoxy coating; and (5) stainless steel segmented liners. A demonstration of a spiral wound lining was done once, but no spiral wound liners are currently in the system. WASD mentioned that it might use shotcrete in the future on a trial basis. A summary of the technologies being used by Miami-Dade for large diameter wastewater remediation are shown in Table 3-23.

Table 3-22. Summary of Small Diameter Wastewater Technologies Used

Small Diameter Technologies
Open Cut (Full Length and Point Repair)
CIPP (Full Length and Sectionals)
Internal Grouting
Degrease
Fold-and-Form & Pipe Bursting rarely

Table 3-23. Summary of Large Diameter Wastewater Technologies Used

Large Diameter Technologies
Open Cut (Majority)
Sliplining
CIPP
Epoxy Coating
Segmental Lining

Sewer lateral rehabilitation, which is done from the mainline to the property line, is typically cheaper when using CIPP versus sliplining. WASD has also used mini-pipe bursting in-house up to 6 in. on 8 to 10 laterals. The lateral inspection program includes the lateral crew monitoring each lateral for up to five minutes to see if it stops flowing during CCTV inspections of the main. If the lateral is continually flowing, the crew will come back out and inspect the lateral further to determine if an illegal connection or leak is causing the continual flow.

WASD also addresses I/I issues with its manholes, which includes the use of technologies such as: (1) manhole replacement; (2) fiberglass repairs, which are done in-house; (3) cementitious coatings, which have not been very successful; and (4) epoxy coatings. Cured-in-place manhole liners have not yet been approved, which involves a free demonstration and monitoring for one year with a decision being made at the end of the year based on performance. WASD reserves the right to remove a product from its approved technologies after more than a year if a product fails down the line.

3.8.3 Technology Selection Methodology. As referenced earlier, WASD performs CCTV inspections on 5 and 10 year cycles for wastewater pipes 2,000 ft and longer and also on two year cycles for transitions from force mains to gravity mains. WASD also performs light night flow monitoring twice a year, once while wet and once while dry, to calculate the flow in gallons per in. diameter per mile. The inspection crews utilize trucks, which are owned by Miami-Dade, which will be upgraded to include Granite XP software. The software is used to store condition assessment data, pipe characteristic data, and GIS maps. Once a field crew performs the inspection, they pass the condition assessment data on to the design evaluation team.

The design evaluation team performs a defect analysis on the data obtained from the field crew to perform a cost analysis of each of the rehabilitation alternatives referenced earlier. The cost analysis includes the following parameters: (1) pipe characteristics (i.e., linear ft and diameter); (2) technology equipment; and (3) site-specific requirements (i.e., pavement restoration and bypass requirements). The design evaluation team also incorporates site photos into its decision-making process by using images from Google Earth. The team uses a tool in Microsoft Access to house cost data, but the rehabilitation/replacement costs are calculated manually. WASD would like to automate the process to be able calculate bid items for its technology options. WASD's typical design evaluation parameters are summarized in Table 3-24.

Table 3-24. Summary of Miami-Dade WASD's Design Evaluation Parameters

Condition Assessment
CCTV Report, Flow Monitoring, and Defect Analysis
Pipe Characteristics
Linear ft and Diameter
Technology Equipment
Specific Equipment Associated with a Particular Technology
Site-Specific Requirements
Pavement Restoration and Bypass

Once WASD determines all of the technologies that are capable of addressing the needs of a specific line, a repair cost analysis is performed. As mentioned earlier, WASD does not record the calculations or document the process of determining the least expensive repair application for each analysis. The cost calculation and method selection process is performed manually for each repair call. For example, a typical section requiring remediation could be an 8 in. pipe, 340 ft long and 8.4 ft deep with four laterals along the alignment and 11 defect locations. The repair cost analysis for CIPP, replacement, sectional liner, and cleaning is shown in Table 3-25.

Table 3-25. Repair Cost Analysis Example

Repair Method	Unit Cost	Laterals	Total
CIPP	\$23.50/lf	\$270/lateral	\$9,070
Open Cut Replacement	\$34.50/lf + \$13,555[1]	\$850/lateral[2]	\$28,685
Sectional Liner	\$975/defect section		\$10,725
Clean, Test, and Seal	\$4.54/lf		\$1,545

[1]Cost for excavation, backfill, and restoration
[2]\$34/ft of lateral (assuming 25 ft of lateral)

3.8.4 Conclusions and User Needs. Miami-Dade WASD bases its final technology decision on what will be the most practical and cost efficient solution in each situation. Mr. Lovett indicated that he would like to automate their current design evaluation and cost analysis process. WASD would be interested in a cost estimating tool for determining the associated regional costs items relating to alternatives for rehabilitation of wastewater pipes. The tool would also need to include technology case histories to provide them with an understanding of how successfully or unsuccessfully technologies have been used by other utilities. The proposed tool would be useful as a training mechanism for municipalities to find out about other alternative technologies that are being used successfully for similar shared conditions.

Contact: Rod Lovett, (786) 268-5025, rodlo@miamidade.gov

4.0: CRITICAL GAPS OF CURRENT MODELS AND APPROACHES

As identified in Sections 2 and 3, few approaches are currently being used by utilities to assist them in determining whether to rehabilitate or replace their existing water and wastewater assets. The literature review identified various models that are capable of evaluating water and wastewater infrastructure conditions and characteristics and producing replacement and rehabilitation technology recommendations. Although the review identified several models capable of the proposed evaluation, very few are being used in practice by water and wastewater utilities. The primary reason is that only two of the models contain all five of the critical components, (i.e., (1) ability to process condition assessment data; (2) contains an extensive method database; (3) performs a technical evaluation of the project conditions and characteristics; (4) performs a costs analysis; and (5) performs a final method ranking) and neither of those are readily available for use. One of the additional utilities surveyed noted the use of a software program for providing a rough idea of applicable construction methods, although the actual method selection and design required a much more detailed review of project conditions (Ariaratnam and MacLeod, 2002). It was also noted that many of the models relied on the use of performance data in determining life cycle costs, yet many technologies and materials have not been subjected to accelerated aging tests and retrospective analyses which can determine the true life cycle of the various technologies.

In addition to the reviewed models, the decision-making approach of eight utilities was thoroughly examined and documented in Section 3. Table 4-1 summarizes the findings and documents the primary mode of decision-making used by each utility.

Table 4-1. Summary of Utility Decision-Making Methodologies

Utility	Water (W) or Wastewater (WW)	In-House Expertise	Consultant Expertise	Tool/Model Support
Dallas	W & WW	Yes	Yes	Technology Selection
Columbus	W & WW	Yes	Yes	Asset Management
New York	W & WW	Yes	Yes	N/A
Indianapolis	WW	Yes	Yes	N/A
Los Angeles	WW	Yes	Yes	Technology Selection
Atlanta	WW	Yes	Yes	Technology Selection
Miami-Dade	WW	Yes	No	N/A
Las Vegas	W	Yes	No	Asset Management

Each of the eight visited utilities and additional surveyed utilities utilized their in-house expertise, in the form of experienced engineers and design manuals, to make renewal decisions supplemented in most cases with the use of outside consultant engineering expertise as well. Asset management tools have been implemented by two of the utilities surveyed, Columbus and Las Vegas. Columbus is in the process of developing two separate tools, one for water and one for wastewater, through collaboration with outside consultants. LVVWD has implemented components from CARE-W (Section 2.3.5) to prioritize its inspection decisions. It has been reported that many utilities have some level of asset management approaches in place, but there is still a large gap between the advances in theory and software tools for asset management and their implementation across a wide range of utilities (EPA, 2010).

Three of the eight utilities surveyed have developed tools capable of technology selection through collaboration with engineering consultants. Table 4-2 summarizes the capabilities of these three tools being used for technology selection decisions.

Table 4-2. Summary of Technology Selection Tools

Utility/Tool	Defect Data	Number of Methods	Technical Evaluation	Cost Analysis	Method Ranking
Dallas, MWH	Yes	3	Yes	Yes	Yes
Los Angeles, SPOT	Yes	4	Yes	No	No
Atlanta, RST	Yes	6	Yes	Yes	Yes

Two of the tools are capable of addressing each of the five critical components documented previously, yet both tools are only used for making wastewater remediation recommendations and not for water decisions. One reason for the limited use of technology selection tools by water utilities is the lack of comfort and experience that these utilities have with innovative and emerging water rehabilitation methods. Utilities are often hesitant to take on the risk of installing new technologies available for water main rehabilitation, which is why most of the utilities surveyed typically replace their water mains. As technologies for water main rehabilitation become more widely accepted and available, there will be a need to help decision-makers to select appropriate technologies.

For each utility participating in the study, inquiries were made as to what types of tools or capabilities they would like to see made available. The overriding areas discussed that would be crucial for any decision tool to be truly useful included: (1) ability to provide more alternative rehabilitation options; (2) use of regional cost data, including the specific various cost items relating to technologies; (3) use of technology case histories, specifically for new technologies; and (4) the contact information of utilities users which have used the technology for further reference material. A summary of needs of each the utilities surveyed is presented in Table 4-3.

Table 4-3. Expressed Needs of Utility Decision Makers

Utility	More Options	Cost Data	Case Studies	Utility Contacts
Dallas	Yes	Yes	Yes	Yes
Columbus	No	Yes	Yes	Yes
New York	Yes	Yes	Yes	Yes
Indianapolis	Yes	Yes	Yes	Yes
Los Angeles	Yes	No	No	No
Atlanta	Yes	Yes	Yes	Yes
Miami-Dade	Yes	Yes	Yes	Yes
Las Vegas	Yes	Yes	Yes	Yes
San Diego	N/A	N/A	N/A	N/A
Nashville	Yes	Yes	Yes	Yes
Phoenix	Yes	Yes	Yes	Yes
Boston	Yes	Yes	No	Yes
Albuquerque	No	No	Yes	No
San Francisco	Yes	No	No	No
Edmonton	Yes	Yes	Yes	No
Virginia Beach	Yes	Yes	Yes	Yes
Calgary	No	Yes	Yes	Yes
Percentage	**81%**	**81%**	**81%**	**75%**

While several of the models discussed in Section 2 provide many alternatives and various forms of cost data, very few contained detailed case studies and contact information for utility users which were both seen as important aspects of any DSS. Multiple utilities commented on how industry interaction and networking between utility users helps to drive the use of alternative techniques. This interaction allows the utility to gain insight into issues which are difficult to quantify such as (i.e., reliability, risk, environmental sustainability, etc.) through other utility's experiences and lessons learned. Once a utility is comfortable with a technique and its known capabilities, they will feel more comfortable recommending it in the proper situation.

Other benefits noted by utilities included the use of such a tool as a training mechanism for less experienced municipalities and their employees. The tool could also be used to train new engineers in the technology selection process and cost evaluation. The tool would need to be user-friendly and require little training or other resources in order to minimize the learning curve for its use. The tool would also need to be customizable to meet utility-specific needs and to be able to integrate it with current cost databases in use by as many utilities as possible.

5.0: RECOMMENDATIONS FOR IMPROVING UPON EXISTING APPROACHES

Based on the numerous models reviewed in Section 2 and the various approaches of the utilities surveyed in Section 3, four models have been identified as offering best practices in terms of enabling rehabilitation versus replacement decisions. The capabilities and limitations of these models and the number of rehabilitation and replacement methods included in each model are summarized in Table 5-1.

Table 5-1. Best Practices in Existing Decision-Making Approaches

Model/Utility Tool	W or WW	Defect Data	Methods	Cost Analysis	Case Studies
Matthews (TAG-R)	W/WW	No	80	Yes	No
Halfawy et al., 2008	WW	Yes	20	Yes	No
Ammar et al., 2010	W	Yes	9	Yes	No
Atlanta (RST)	WW	Yes	6	Yes	No

Each of the identified approaches is capable of many of the critical analyses a DSS must have including a cost analysis and a technical evaluation of a large number of rehabilitation/replacement methods. The primary gap in all approaches is the lack of case study information, which was highlighted by each surveyed utility as being crucial to the transfer of knowledge. All approaches, except for the Matthews/TAG-R approach, focus only on one type of system, either water or wastewater. The area needing to be improved upon in the Matthews approach includes the use of defect data for wastewater systems and breakage and deterioration data for water systems.

It is feasible to substantially improve on all models by incorporating the best aspects into a single, comprehensive model for decision support. TAG-R contains the most robust method database and industry vetted technical evaluation process. Halfawy et al. (2008) contains a viable approach for including defect codes into the wastewater technology selection process and Ammar et al. (2010) incorporates breakage and deterioration data into the water technology selection process. The Atlanta RST has the most developed platform for including cost data and parameters for specific technologies which could be expanded for each of the technologies available in TAG-R. Once a combination of these aspects is incorporated into one system, the final component would be the inclusion of a case study database. Table 5-2 outlines the components necessary for building a useful case study database. The task of collecting the required data for building such a database is feasible and would require the resources and networking capabilities of an experienced team closely tied to all aspects of the water and wastewater industry.

Table 5-2. Cast Study Database Components

Component	Description
Technology/Method	Sortable by specific technology/vendor and application.
Project Specifics	Field and pipe conditions leading to method selection.
Lessons Learned	Lessons learned from technology installations and demonstrations.
QA/QC	Actions taken and inclusion of product testing references.
Project Costs	Specific cost considerations and ranges.
Utility Information	Background and system information of utility.
Contact Information	Contact information of the utility owner, designer, vendor, and installer.

Currently, users will be able to utilize the available tools and models in their limited, but effective capacities. As a result of this review, several improvements were identified that could be implemented to develop a more comprehensive and fully-functional decision support approach as described above. In order to develop an improved model, the team would need to have the DSS development background to incorporate the two aspects into one useable application. The development of such a system would require support from agencies such as WERF, WaterRF, NASSCO, NUCA, and the EPA to ensure that all of the key stakeholders were involved in the program development and implementation.

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